

AN INVESTIGATION OF THE  
EFFECT OF DIRECT WATER  
INJECTION ON DETONATION

BY

ROBERT EMMET SEIBELS, JR.  
THOMAS WASHINGTON, JR.

AND

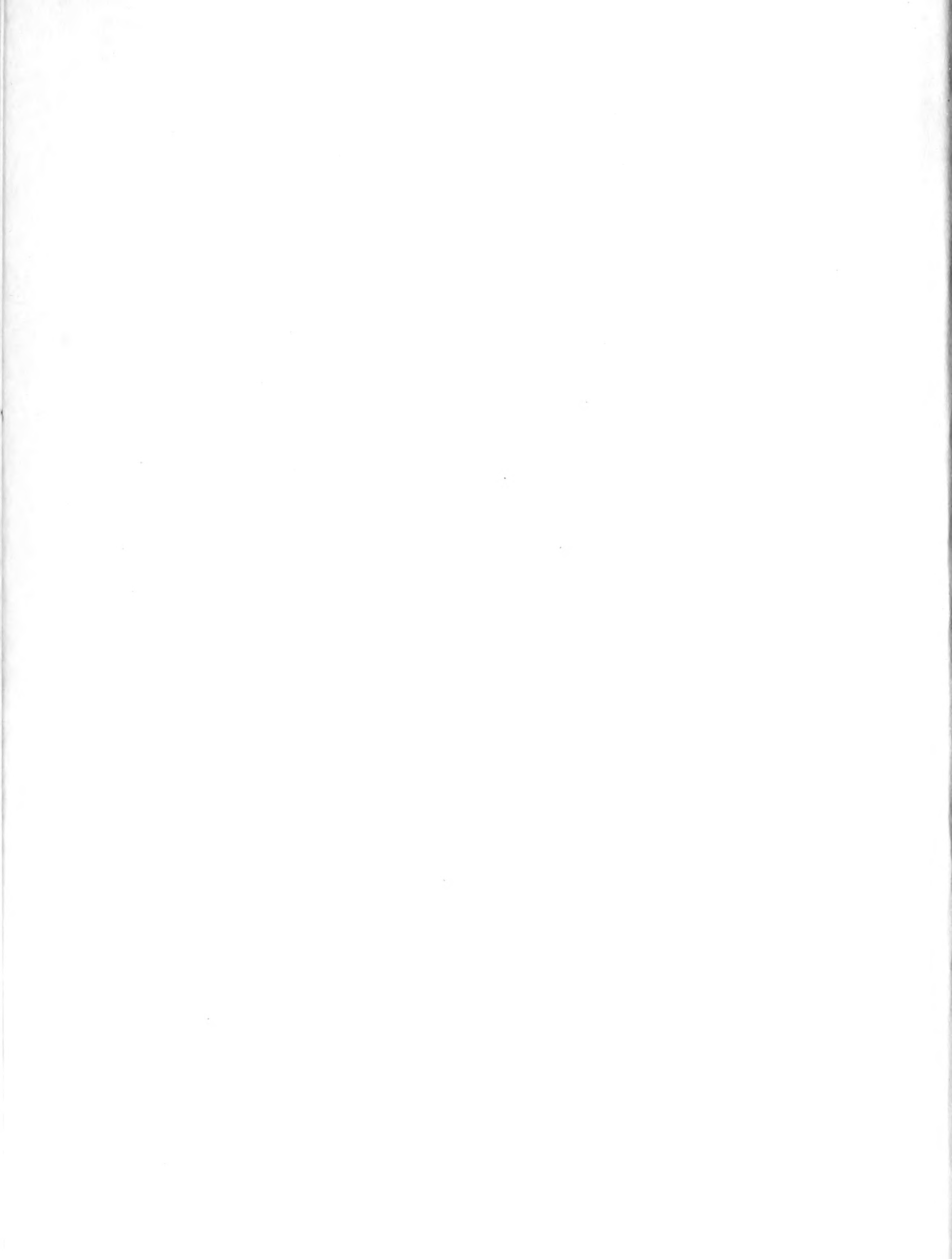
J. R. MacLACHLAN

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DIRECT WATER INJECTION ON DETONATION

by

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Submitted in Partial Fulfillment of the  
requirements for the  
Degree of Master of Science  
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from the  
Massachusetts Institute of Technology  
1946 ✓

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Cambridge, Massachusetts  
1 June 1946

Professor George W. Swett  
Secretary of the Faculty  
Massachusetts Institute of Technology  
Cambridge, Massachusetts

Dear Sir:

A thesis entitled "An Investigation of the Effect of Direct Water Injection on Detonation" is herewith submitted in partial fulfillment of the requirements for the degree of Master of Science in Aeronautical Engineering. .

The following information  
 was obtained from the  
 investigation of the  
 subject's activities during the  
 period of the investigation.

44,157,000,000.

*[Faint handwritten notes and markings are visible across the page.]*

## ACKNOWLEDGMENTS

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APPENDIX

The authors wish to express their grateful appreciation of the assistance rendered by the entire staff of the Lowry Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts. They are particularly indebted to Professor C. F. Taylor, Assistant Professor A. R. Kowarski, Assistant Professor J. H. ... and Mr. J. L. ...

# AN INVESTIGATION OF THE EFFECT OF DIRECT WATER INJECTION ON DETONATION

## SUMMARY

The purpose of this project was to investigate the effects of direct water injection on detonation. The following conclusions were reached:

1. The addition of water at a constant fuel-air ratio permits the attainment of higher indicated mean effective pressures without detonation. This effect is more pronounced for low fuel-air ratios than for high fuel-air ratios.
2. At a fixed water-fuel ratio, the fuel-air ratio at which the maximum detonation free indicated mean effective pressure occurs increases as compression ratio decreases.
3. At a constant isfc, detonation free imep increases with water-fuel ratio. At fuel-air ratios below .09, islc increases very rapidly with increase in imep while at fuel-air ratios above .09, islc decreases slightly with imep increase.
4. Increasing water-fuel ratio at low (cruising) fuel-air ratios results in a decrease in isfc, but at the expense of a prohibitive increase in islc.
5. Fuel is considerably more effective than water as an anti-detonant at low (cruising) fuel-air ratios.
6. At high (take-off) fuel-air ratios, water is effective as an anti-detonant, while the use of additional

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fuel for this purpose actually results in a decrease of imep.

7. Indicated thermal efficiency is not affected by the addition of water.

8. Water injection permits the use of higher compression ratios by increasing detonation free imep to take-off values. This permits the designer to take advantage of the greatly improved fuel economy in the cruising range resulting from the use of high compression ratios.





## AN INVESTIGATION OF THE EFFECT OF DIRECT WATER INJECTION ON DETONATION

### INTRODUCTION

It is an established fact that, for a fixed inlet pressure and temperature, increase of compression ratio of an engine increases power output slightly but produces a decided improvement in fuel economy. Therefore, designers of internal combustion engines would desire to use high compression for the purpose of obtaining fuel economy. But increase of compression ratio is limited because of detonation at high powers. Thus, the attempt to improve fuel economy by increasing compression may render an engine unsuitable for use because of the reduction of power for take-off and full load.

The limitations of increased compression ratio on take-off and full load are now being improved by the addition of water to the fuel-air mixture. During the past war, the method of spraying water into the inlet manifold was used with considerable success. According to some reports, the power for take-off was increased by 15% to 30%. A second method of adding water to the fuel-air mixture would be by direct injection of water into the cylinder. This second method has had very little investigation and no practical use at the present date. It is the object of this project to investigate the effect on detonation of direct water injection into the cylinder.



The project was conducted at the Sloan Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, by Comdr. R. E. Seibels, Jr., USN, Comdr. T. Washington, Jr., USN, and Lt. Comdr. J. R. MacLachlan, USN. Mr. W. A. Leary of the M.I.T. staff was supervisor.

#### EQUIPMENT

The test equipment included a variable-compression, one-cylinder Coordinating Fuel Research Engine delivering power to a dynamometer. Fuel vaporization was accomplished by spraying fuel into a heated vaporizing tank. An injection pump and an injection nozzle were used to spray water directly into the cylinder. Figs. 1, 2, 3, and 4 are photographs of the arrangement of equipment. Fig. 5 is a block diagram of the installation set-up.

The engine of this project was a standard variable-compression, one-cylinder CFR Engine. This engine had a 3.25 in. bore, a 4.5 in. stroke and a 37.33 cu. in. displacement. Compression could be set at any desired compression ratio between 4 and 10. This standard CFR Engine is fully described in Ref. 1.

The dynamometer was a 5 HP motor-generator set manufactured by the Star Electric Motor Company. It was used as a motor to turn over the CFR Engine for starting or motoring, and as a generator to absorb the power delivered by that engine.

1. The first part of the report is a summary of the work done during the year. It is a brief statement of the results of the work, and is intended to give a general idea of the progress made.

2. The second part of the report is a detailed account of the work done during the year. It is a full and complete statement of the work, and is intended to give a detailed account of the progress made.

3. The third part of the report is a summary of the work done during the year. It is a brief statement of the results of the work, and is intended to give a general idea of the progress made.

4. The fourth part of the report is a summary of the work done during the year. It is a brief statement of the results of the work, and is intended to give a general idea of the progress made.

The gasoline used in this experiment was standard 80 octane unleaded aviation gasoline. This gasoline was taken from the mains of the Sloan Laboratory and passed through a fuel rotometer to the fuel pump. A Bosch injection pump driven by a small electric motor forced the gasoline at high pressure through an injection nozzle into a heated vaporizing tank. A vernier adjustment on the Bosch pump allowed accurate control of fuel flow.

Air to the vaporizing tank could be taken either from the test room at atmospheric pressure, or from the laboratory high pressure main. A Nash Hytor L-5 Compressor driven by a Sprague Electrical Dynamometer supplied the high pressure air. The air was metered through a calibrated orifice and drawn into the vaporizing tank.

Distilled water was used for injection into the cylinder. This distilled water was stored in a one gallon glass jug. From the jug the water flowed by gravity to a constant level float chamber and thence through a water rotometer to the water pump. The water pump was an engine driven Bosch injection pump equipped with a vernier adjustment for close control of flow. The pump forced water at high pressure through a Bendix KC 50S1 injection nozzle (Fig. 6) into the cylinder at a point opposite the spark plug.

Detonation was detected by a detonation pickup and oscillograph. The pickup was one of the pressure type, being



sensitive to the rate of change of pressure ( $dp/dt$ ). The oscillograph was a Dumont 208 Cathode-Ray Oscillograph.

Other apparatus used in preparation for this experiment included balance scales, MIT Pressure-Crank Machine, and MIT Transfer Machine which transferred pressure-crank readings to pressure volume. The latter two machines are described in Appendix II of Ref. 2 and Appendix B of Ref. 3, respectively.

The water injection equipment of this experiment leaves much to be desired. The time of the start of injection can be accurately controlled. But, unfortunately, the length of time of injection varies with the amount of water injected. Detonation takes place somewhere near to the same crank angle for all powers and fuel-air ratios. It would be desirable to have the angle of injection time remain constant no matter what the rate of water flow, and to so adjust the time of injection as to best suppress detonation. With the present apparatus, some of the benefit is lost because the time of mid-point of injection varies with water flow. Optimum utilization of water cannot be realized because at low and moderate flow rates, some of it may be injected too early for best detonation suppression, while at high flow rates, part of the water is injected too late to be effective.





## PRELIMINARY PROCEDURE

It was necessary, prior to the commencement of this investigation, to devote considerable time and labor to the arrangement of the test apparatus shown in Figs. 1 through 4. The purpose was two-fold: first, to eliminate or to reduce as far as possible the effects of those variables not pertinent to this investigation; and second, to permit accurate control of all essential variables.

As further preliminaries it was necessary to calibrate both the fuel and water rotometers, the water injection apparatus, and to calibrate the dynamometer mercury manometer in terms of indicated mean effective pressure. As a final preliminary to this investigation, the water injection apparatus was timed to insure start of injection at the desired crank angle.

Calibration curves of the fuel and water rotometers made from the data of Table I appear in Fig. 7. The method of calibration followed in both cases consisted essentially of weighing the amount of liquid which passed through the rotometer in a measured interval of time, during which the rotometer setting was maintained at a constant value. The mass flow per second was calculated and plotted against rotometer setting.

To calibrate the dynamometer mercury manometer, indicator cards were taken using MIT Pressure Crank Angle Machine,



following the procedure outlined in Ref. 2, simultaneously with mercury manometer readings. From the indicator cards, indicated mean effective pressure was determined, using MIT Transfer Machine to transfer pressure crank values to pressure volume values. (Ref. 3). A plot of indicated mean effective pressure versus inches of mercury made from data of Table II appears in Fig. 8.

The calibration of the water injection apparatus in terms of water rotometer reading and duration of water spray in degrees of crank angle,  $\alpha$ , is shown in Fig. 9. The start of the spray was set to occur at top center by means of an adjustable coupling on the water pump drive shaft and a stroboscope timed to flash at top center. Top center, itself, was determined by the standard CFR Engine calibrated brass spark timing ring and a flashing neon light. It was found as shown in Fig. 9 that varying the water rotometer setting varied the duration of injection in degrees of crank angle, although the start of injection remained fixed at top center.

In order to determine the optimum angle at which to start injection, the following steps were taken. The compression ratio was set at 6.6, and the fuel-air and water-fuel ratios were set arbitrarily at .08 and .8, respectively. The crank angle at which injection starts and the mass rate of air flow were then varied until, by trial and error, the maximum indicated mean effective pressure without detonation



was obtained. The optimum angle corresponding to this condition was thus found to be  $18^{\circ}$  after top center. In all subsequent tests in which water was utilized, injection was started at this point. It is realized that this  $18^{\circ}$  setting probably was not the optimum angle for the entire range of fuel-air ratios and compression ratios. This setting was selected as a compromise in order to reduce the number of variables of the experiment. Since the conditions imposed during selection of this  $18^{\circ}$  angle for start of injection were about average, the setting is probably near optimum for the vast majority of the readings of this project.

#### PROCEDURE

The general plan adhered to in this investigation appears below. The following set of operating conditions was adopted as standard: oil temperature  $160^{\circ}\text{F}$ , oil pressure 35 psi., inlet temperature  $140^{\circ}\text{F}$ , jacket temperature  $212^{\circ}\text{F}$ , and engine speed 1200 RPM. The compression ratio was set at 6.2. Test data were taken for five fuel-air ratios - .064 (good cruising), .07, .08 (best power), .09 and .10. For each fuel-air ratio detonation limited indicated mean effective pressure was determined by means of a cathode-ray oscillograph for water-fuel ratios of from 0 to over 1.0. Curves of detonation limited indicated mean effective pressure at various fuel-air ratios are plotted in Fig. 10 from the data of Table III.



The procedure described above was repeated for compression ratios of 6.6, 7.0, and 7.4. The resulting data obtained appear in Tables IV through VI. The corresponding curves are drawn in Figs. 11 through 13.

A warming up period was required as a daily preliminary to the making of record runs. The CFR Engine required approximately one hour before steady operating conditions were obtained with respect to oil pressure and temperature, jacket temperature, inlet pressure, and particularly inlet temperature. To reduce the delay involved in warming up, oil temperature could be raised by means of an electric oil heater in the crank case and engine jacket temperature by means of a steam bleed. During the warm-up and actual runs, inlet temperature was regulated by varying the amount of steam admitted to the jacket surrounding the vaporizing tank.

When steady operating conditions were obtained and with the compression ratio set at 6.2, a fuel-air ratio of .064 (without water) was set by simultaneously varying the mass rates of flow of both air and fuel until, by trial and error, the desired fuel-air ratio was obtained just as incipient detonation occurred. In this way, the detonation limited indicated mean effective pressure at a zero water-fuel ratio for these conditions was obtained. The mass rate of air flow was then increased. At the same time, the resulting detonation was suppressed by the introduction of an excessive amount of water. Next, the mass rate of fuel flow was increased un-





til a fuel-air ratio of .064 was again obtained. By reducing the amount of water until a condition of incipient detonation again existed, the detonation limited indicated mean effective pressure and the corresponding water-fuel ratio were readily determined. The compression ratio was held constant at 6.2, and the above procedure followed for fuel-air ratios of .07, .08, .09, and .10. In this manner the family of curves shown in Fig. 10 were determined.

The curves of Figs. 11, 12, and 13 were determined in the same manner from the data of Tables IV, V, and VI. The compression was varied through 6.6, 7.0, and 7.4. In order to obtain more readily comparable results the same series of fuel-air ratios were used in each case.

Additional points at a zero water-fuel rate were obtained at a compression ratio of 7.4, for fuel-air ratios of .075, .085, .095, and .11 in order to compare the effectiveness of water versus fuel as anti-detonants. This data is included in Table VI.

is included in the VI.

## RESULTS AND DISCUSSION

The effect of water-fuel ratio on indicated mean effective pressure at compression ratios of 6.2, 6.6, 7.0, and 7.4 is shown in Figs. 10, 11, 12, and 13, respectively. To obtain readily comparable results, the following fuel air ratios were used throughout: .064, .07, .08, .09, and .10. In Fig. 14 are shown the relative effects of fuel and water as detonation suppressors. A cross plot at a constant indicated mean effective pressure of 115 p.s.i.a., of compression ratio versus water-fuel ratio at various fuel-air ratios is shown in Fig. 15.

It may be seen from Fig. 10 that the addition of water accomplished at a constant fuel-air ratio, permits the attainment of a higher indicated mean effective pressure without detonation. It may be seen further from Fig. 10 that the slopes of the curves became progressively shallower as the mixture becomes richer. This means that the effect of water addition is more pronounced at low fuel-air ratios. Similar trends are noted for all compression ratios investigated. (Figs. 11, 12, and 13).

At a compression ratio of 7.4 (Fig. 13) for any given water-fuel ratio, the maximum detonation free indicated mean effective pressure occurs at a fuel-air ratio of .09. As the compression ratio is decreased (Figs. 12, 11, and 10) the maximum indicated mean effective pressure for a given water-



fuel ratio appears to occur at progressively higher fuel-air ratio. Thus, for a compression ratio of 6.2, the optimum detonation free fuel-air ratio appears to be slightly greater than .10. This phenomenon is considered to be characteristic of this 80-octane unleaded aviation gasoline, and would not necessarily recur for another gasoline.

Superimposed on Fig. 13 are curves of constant indicated specific fuel consumption (isfc) and indicated specific liquid (fuel plus water) consumption (islc). An examination of the figure shows that at a constant isfc, detonation free imep obtainable increases with water-fuel ratio. However, this increase of imep at a constant isfc is obtained at the expense of a considerable increase in islc, as long as the fuel-air ratio remains below .09. When the fuel-air ratio exceeds .09, increasing the water-fuel ratio at a constant isfc is accompanied by two effects: first, a slight increase in imep; and second, a slight decrease in islc. Further, at a given water-fuel ratio and at a fuel-air ratio of .10 or greater, a decrease of fuel-air ratio results in both an increase in detonation free imep and a decrease in islc. Translating the above into practical applications, although increasing water fuel for a given cruise power output results in a lower isfc, the increase in islc is prohibitive.



Continuing in the same vein, Fig. 15 was plotted in order to compare the effects of additional water and fuel as detonation suppressors, both at a cruising fuel-air ratio and at a fuel-air ratio of .09, which was considered to be within the take-off range. Fuel was found to be considerably more effective than water at the low fuel-air ratio. The reverse was true at the high fuel-air ratio. Actually the use of additional fuel as a detonation suppressor at the high fuel-air ratio resulted in a decrease of imep, while the addition of water permits an increase in imep. It is evident that in order to attain high values of imep (in this case, 115) water must be used since these values cannot be attained with fuel alone.

By classical theory, the indicated thermal efficiency is a function both of compression ratio and fuel-air ratio. For a fixed compression ratio and fuel-air ratio, indicated thermal efficiency would be constant if the addition of water had no effect. Tables III through VI show that for a given fuel-air ratio and compression ratio, the indicated thermal efficiency remains constant regardless of the water-fuel ratio. It is therefore concluded that indicated thermal efficiency is not affected by the addition of water.

High compression ratios with their resulting high efficiencies are desirable in order to give fuel economy in the cruise range, but take-off powers are limited by detonation of the fuel-air mixture. The advantage of water in-





jection is that it permits use of high compression ratios, while providing sufficient power for take-off. The curves of Fig. 15 were drawn to illustrate this effect. If an imep of 115 p.s.i.a. was required for the take-off, the compression ratio would be limited to approximately 6.7 in the absence of water. By using a water-fuel ratio of about 1.3, the compression ratio may be increased to 7.4. Since take-off powers would be used for only a short period, the high water-fuel ratio of 1.3 is not prohibitive. Similar trends are apparent for the remaining fuel-air ratios considered. Thus, the airplane designer, by using the high compression ratios and accepting the high water-fuel ratios required for take-off, may obtain greatly improved fuel economy in the cruising range.

In conclusion it may be stated that the percent increase in imep obtainable by using a water-fuel ratio of about 1.0 is in the order of 15%. Thus, the method of direct water injection used in this investigation compares favorably with the method of adding water to the induction system. Had the mechanics of direct water injection used herein been more refined, this method might have proven its superiority over the water-into-induction-system method.



## CONCLUSIONS

As a result of this investigation of the effect on detonation of direct water injection into the cylinder of an engine operating on 80 octane unleaded aviation gasoline, the following conclusions were reached:

1. The addition of water at a constant fuel-air ratio permits the attainment of higher indicated mean effective pressures without detonation. This effect is more pronounced for low fuel-air ratios than for high fuel-air ratios.
2. At a fixed water-fuel ratio, and for this gasoline, the fuel-air ratio at which the maximum detonation free indicated mean effective pressure occurs increases as compression ratio decreases.
3. At a constant isfc, detonation free imep increases with water-fuel ratio. At fuel-air ratios below .09, islc increases very rapidly with increase in imep while at fuel-air ratios above .09, islc decreases slightly as imep increases.
4. Increasing water-fuel ratio at low (cruising) fuel-air ratios results in a decrease in isfc, but at the expense of a prohibitive increase in islc.
5. Fuel is considerably more effective than water as an anti-detonant at low (cruising) fuel-air ratios.

1. Introduction

The purpose of this study is to investigate the effects of various factors on the growth and development of the human body. The study is based on a review of the literature and a series of experiments conducted over a period of six months. The results of the study are presented in the following sections.

The first section discusses the factors that influence the growth and development of the human body. These factors include genetics, nutrition, and environment. The second section describes the methods used in the study, including the selection of subjects and the design of the experiments. The third section presents the results of the study, showing the effects of the different factors on the growth and development of the human body. The fourth section discusses the implications of the study for the field of human growth and development.

The study found that genetics, nutrition, and environment all have a significant effect on the growth and development of the human body. Genetics is the most important factor, followed by nutrition and then environment. The study also found that the effects of these factors are not always additive, and that there are complex interactions between them. The results of the study have important implications for the field of human growth and development, and for the development of interventions to improve human health and well-being.

6. At high (take-off) fuel-air ratios, water is effective as an anti-detonant, while the use of additional fuel for this purpose actually results in a decrease of imep.
7. Indicated thermal efficiency is not affected by the addition of water.
8. Water injection permits the use of higher compression ratios by increasing detonation free imep to take-off values. This permits the designer to take advantage of the greatly improved fuel economy in the cruising range resulting from the use of high compression ratios.



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2. N A C A Technical Note No. 675, The Charging Process in a High Speed, Single-Cylinder, Four-Stroke Engine, by Reynolds, Schechter, and Taylor.
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# Formulae for Computations

## CFR Engine Data

$$\text{Bore} = 3.25" \quad \text{Piston Area} = 8.296 \text{ in}^2$$

$$\text{Stroke} = 4.50" \quad \text{Displacement Volume} = 37.33 \text{ in}^3$$

$$\text{rpm} = 1200 \text{ (constant)}$$

$$\text{imep} = \frac{\text{Area P-V Diagram}}{5} \times \text{Spring Constant, psia}$$

$$\text{IHP} = \frac{\text{imep} \times \text{Piston Area} \times \frac{\text{Stroke}}{12} \times \frac{\text{rpm}}{2}}{33000} = .0566 \times \text{imep}$$

$$\text{ISFC} = \frac{\text{lb. fuel/hr.}}{\text{IHP}} = \frac{\dot{M}_f \times 3600}{\text{IHP}}$$

$$\text{ISWC} = \frac{\text{lb. water/hr.}}{\text{IHP}} = \frac{\dot{M}_w \times 3600}{\text{IHP}}$$

$$\text{ISLC} = \frac{\text{lb. Liquid/hr.}}{\text{IHP}} = \frac{3600}{\text{IHP}} (\dot{M}_f + \dot{M}_w) = \text{ISFC} + \text{ISWC}$$

$$\eta_i = \frac{\text{IHP} \times 2545}{3600 \times \dot{M}_f \times E_c} = \frac{\text{IHP} \times 2545}{\dot{M}_f \times 3600 \times 19270} = \frac{\text{IHP}}{27250 \dot{M}_f}$$



Units

Area P-V Diagram	=	Square inches
Spring Constant	=	Pounds per inch
imep	=	Indicated mean effective pressure, psia
IHP	=	Horsepower
$\dot{M}_f$	=	Fuel flow, pounds per second
$\dot{M}_w$	=	Water flow, pounds per second
ISFC	=	Indicated Specific Fuel Consumption, $\frac{\text{lb/hr}}{\text{IHP}}$
ISWC	=	Indicated Specific Water Consumption, $\frac{\text{lb/hr}}{\text{IHP}}$
ISLC	=	Indicated Specific Liquid Consumption, $\frac{\text{lb/hr}}{\text{IHP}}$
$\eta_1$	=	Indicated Thermal Efficiency

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93. 2125-2126	93. 2125-2126
94. 2127-2128	94. 2127-2128
95. 2129-2130	95. 2129-2130
96. 2131-2132	96. 2131-2132
97. 2133-2134	97. 2133-2134
98. 2135-2136	98. 2135-2136
99. 2137-2138	99. 2137-2138
100. 2139-2140	100. 2139-2140
101. 2141-2142	101. 2141-2142
102. 2143-2144	102. 2143-2144
103. 2145-2146	103. 2145-2146
104. 2147-2148	104. 2147-2148
105. 2149-2150	105. 2149-2150
106. 2151-2152	106. 2151-2152
107. 2153-2154	107. 2153-2154
108. 2155-2156	108. 2155-2156
109. 2157-2158	109. 2157-2158
110. 2159-2160	110. 2159-2160
111. 2161-2162	111. 2161-2162
112. 2163-2164	112. 2163-2164
113. 2165-2166	113. 2165-2166
114. 2167-2168	114. 2167-2168
115. 2169-2170	115. 2169-2170
116. 2171-2172	116. 2171-2172
117. 2173-2174	117. 2173-2174
118. 2175-2176	118. 2175-2176
119. 2177-2178	119. 2177-2178
120. 2179-2180	120. 2179-2180
121. 2181-2182	121. 2181-2182
122. 2183-2184	122. 2183-2184
123. 2185-2186	123. 2185-2186
124. 2187-2188	124. 2187-2188
125. 2189-2190	125. 2189-2190
126. 2191-2192	126. 2191-2192
127. 2193-2194	127. 2193-2194
128. 2195-2196	128. 2195-2196
129. 2197-2198	129. 2197-2198
130. 2199-2200	130. 2199-2200
131. 2201-2202	131. 2201-2202
132. 2203-2204	132. 2203-2204
133. 2205-2206	133. 2205-2206
134. 2207-2208	134. 2207-2208
135. 2209-2210	135. 2209-2210
136. 2211-2212	136. 2211-2212
137. 2213-2214	137. 2213-2214
138. 2215-2216	138. 2215-2216
139. 2217-2218	139. 2217-2218
140. 2219-2220	140. 2219-2220
141. 2221-2222	141. 2221-2222
142. 2223-2224	142. 2223-2224
143. 2225-2226	143. 2225-2226
144. 2227-2228	144. 2227-2228
145. 2229-2230	145. 2229-2230
146. 2231-2232	146. 2231-2232
147. 2233-2234	147. 2233-2234
148. 2235-2236	148. 2235-2236
149. 2237-2238	149. 2237-2238
150. 2239-2240	150. 2239-2240
151. 2241-2242	151. 2241-2242
152. 2243-2244	152. 2243-2244
153. 2245-2246	153. 2245-2246
154. 2247-2248	154. 2247-2248
155. 2249-2250	155. 2249-2250
156. 2251-2252	156. 2251-2252
157. 2253-2254	157. 2253-2254
158. 2255-2256	158. 2255-2256
159. 2257-2258	159. 2257-2258
160. 2259-2260	160. 2259-2260
161. 2261-2262	161. 2261-2262
162. 2263-2264	162. 2263-2264
163. 2265-2266	163. 2265-2266
164. 2267-2268	164. 2267-2268
165. 2269-2270	165. 2269-2270
166. 2271-2272	166. 2271-2272
167. 2273-2274	167. 2273-2274
168. 2275-2276	168. 2275-2276
169. 2277-2278	169. 2277-2278
170. 2279-2280	170. 2279-2280
171. 2281-2282	171. 2281-2282
172. 2283-2284	172. 2283-2284
173. 2285-2286	173. 2285-2286
174. 2287-2288	174. 2287-2288
175. 2289-2290	175. 2289-2290
176. 2291-2292	176. 2291-2292
177. 2293-2294	177. 2293-2294
178. 2295-2296	178. 2295-2296
179. 2297-2298	179. 2297-2298
180. 2299-2300	180. 2299-2300
181. 2301-2302	181. 2301-2302
182. 2303-2304	182. 2303-2304
183. 2305-2306	183. 2305-2306
184. 2307-2308	184. 2307-2308
185. 2309-2310	185. 2309-2310
186. 2311-2312	186. 2311-2312
187. 2313-2314	187. 2313-2314
188. 2315-2316	188. 2315-2316
189. 2317-2318	189. 2317-2318
190. 2319-2320	190. 2319-2320
191. 2321-2322	191. 2321-2322
192. 2323-2324	192. 2323-2324
193. 2325-2326	193. 2325-2326
194. 2327-2328	194. 2327-2328
195. 2329-2330	195. 2329-2330
196. 2331-2332	196. 2331-2332
197. 2333-2334	197. 2333-2334
198. 2335-2336	198. 2335-2336
199. 2337-2338	199. 2337-2338
200. 2339-2340	200. 2339-2340
201. 2341-2342	201. 2341-2342
202. 2343-2344	202. 2343-2344
203. 2345-2346	203. 2345-2346
204. 2347-2348	204. 2347-2348
205. 2349-2350	205. 2349-2350
206. 2351-2352	206. 2351-2352
207. 2353-2354	207. 2353-2354
208. 2355-2356	208. 2355-2356
209. 2357-2358	209. 2357-2358
210. 2359-2360	210. 2359-2360
211. 2361-2362	211. 2361-2362
212. 2363-2364	212. 2363-2364
213. 2365-2366	213. 2365-2366
214. 2367-2368	214. 2367-2368
215. 2369-2370	215. 2369-2370
216. 2371-2372	216. 2371-2372
217. 2373-2374	217. 2373-2374
218. 2375-2376	218. 2375-2376
219. 2377-2378	219. 2377-2378
220. 2379-2380	220. 2379-2380
221. 2381-2382	221. 2381-2382
222. 2383-2384	222. 2383-2384
223. 2385-2386	223. 2385-2386
224. 2387-2388	224. 2387-2388
225. 2389-2390	225. 2389-2390
226. 2391-2392	226. 2391-2392
227. 2393-2394	227. 2393-2394
228. 2395-2396	228. 2395-2396
229. 2397-2398	229. 2397-2398
230. 2399-2400	230. 2399-2400
231. 2401-2402	231. 2401-2402
232. 2403-2404	232. 2403-2404
233. 2405-2406	233. 2405-2406
234. 2407-2408	234. 2407-2408
235. 2409-2410	235. 2409-2410
236. 2411-2412	236. 2411-2412
237. 2413-2414	237. 2413-2414
238. 2415-2416	238. 2415-2416
239. 2417-2418	239. 2417-2418
240. 2419-2420	240. 2419-2420
241. 2421-2422	241. 2421-2422
242. 2423-2424	242. 2423-2424
243. 2425-2426	243. 2425-2426
244. 2427-2428	244. 2427-2428
245. 2429-2430	245. 2429-2430
246. 2431-2432	246. 2431-2432
247. 2433-2434	247. 2433-2434
248. 2435-2436	248. 2435-2436
249. 2437-2438	249. 2437-2438
250. 2439-2440	250. 2439-2440
251. 2441-2442	251. 2441-2442
252. 2443-2444	252. 2443-2444
253. 2445-2446	253. 2445-2446
254. 2447-2448	254. 2447-2448
255. 2449-2450	255. 2449-2450
256. 2451-2452	256. 2451-2452
257. 2453-2454	257. 2453-2454
258. 2455-2456	258. 2455-2456
259. 2457-2458	259. 2457-2458
260. 2459-2460	260. 2459-2460
261. 2461-2462	261. 2461-2462
262. 2463-2464	262. 2463-2464
263. 2465-2466	263. 2465-2466
264. 2467-2468	264. 2467-2468
265. 2469-2470	265. 2469-2470
266. 2471-2472	266. 2471-2472
267. 2473-2474	267. 2473-2474
268. 2475-2476	268. 2475-2476
269. 2477-2478	269. 2477-2478
270. 2479-2480	270. 2479-2480
271. 2481-2482	271. 2481-2482
272. 2483-2484	272. 2483-2484
273. 2485-2486	273. 2485-2486
274. 2487-2488	274. 2487-2488
275. 2489-2490	275. 2489-2490
276. 2491-2492	276. 2491-2492
277. 2493-2494	277. 2493-2494
278. 2495-2496	278. 2495-2496
279. 2497-2498	279. 2497-2498
280. 2499-2500	280. 2499-2500
281. 2501-2502	281. 2501-2502
282. 2503-2504	282. 2503-2504
283. 2505-2506	283. 2505-2506
284. 2507-2508	284. 2507-2508
285. 2509-2510	285. 2509-2510
286. 2511-2512	286. 2511-2512
287. 2513-2514	287. 2513-2514
288. 2515-2516	288. 2515-2516
289. 2517-2518	289. 2517-2518
290. 2519-2520	290. 2519-2520
291. 2521-2522	291. 2521-2522
292. 2523-2524	292. 2523-2524
293. 2525-2526	293. 2525-2526
294. 2527-2528	294. 2527-2528
295. 2529-2530	295. 2529-2530
296. 2531-2532	296. 2531-2532
297. 2533-2534	297. 2533-2534
298. 2535-2536	29

TABLE I

## Calibration of Fuel and Water Rotometers

Water Rotometer Calibration 3/14/46      T° = 81				Gasoline Rotometer Calibration 3/15/46      T° = 66			
<u>Roto Reading</u>	<u>Wt Gms</u>	<u>Time Sec</u>	<u>lbs/sec</u>	<u>Roto Reading</u>	<u>Wt Gms</u>	<u>Time Sec</u>	<u>lbs/sec</u>
7.55	10	72.7	.000303	9.7	20	38.3	.00115
8.1	10	64.35	.000348	8.95	20	43.4	.001018
6.6	10	105.95	.000208	8.45	20	46.7	.000943
7.1	10	94.3	.000234	7.85	20	50.4	.000874
17.1	20	29.9	.001473	7.25	20	55.8	.000789
14.95	20	39.0	.00113	5.5	20	79.6	.000553
12.8	20	53.8	.00082	5.9	20	71.9	.000613
5.1	10	229.5	.000096	6.35	20	64.6	.000681
15.9	20	34.8	.001268	6.8	10	29.6	.000745
13.3	20	46.85	.00094	5.15	10	42.5	.000519
10.1	20	82.95	.000532	3.65	10	66.2	.000332
13.8	20	45.55	.000969	4.2	10	53.45	.000412
11.05	20	70.25	.000625	10.4	20	35.5	.001242
8.2	10	65.5	.000337	11.05	20	33.15	.001329
8.75	10	56.75	.000389	11.45	20	29.8	.00148
9.4	10	47.8	.000461	11.8	20	29.55	.001491
5.65	10	151.2	.000146	12.05	20	28.75	.001535
5.8	10	141.65	.000156	4.4	10	50.35	.000439
12.3	20	57.7	.000764	6.25	10	33.9	.000651
11.1	20	70	.00063	6.7	10	31.65	.000696
10.65	20	76.1	.000595	6.85	10	30.3	.000729
9.6	10	56.25	.000392	8.95	20	21.5	.001026
11.4	20	66.2	.000666	9.45	20	19.6	.001124
12.1	20	59.4	.000741	10.0	20	18.1	.001218
7.1	10	96.65	.000228	8.9	20	19.3	.001022
7.7	10	72.75	.000303	11.4	20	15.75	.0014
6.25	10	120.35	.000183	10.65	20	15.95	.00138
13.65	20	45.3	.000973	8.05	20	24.5	.0009
14.5	20	41.4	.001064	7.6	20	26.1	.000845
15.5	20	36.1	.00122	9.25	20	20.65	.001065
13.3	20	47.7	.000925	10.3	20	17.8	.001239
13.8	20	45.7	.000965	9.75	20	19.3	.001141
13.65	20	45.6	.000966	10.1	20	18.3	.0012
13.3	20	49.05	.000900				

Figure 1

63. 205. 3.

18. 1911

2017-2018 2019-2020

FIGURE 1. The effect of the concentration of the  $\text{Ca}^{2+}$  solution on the rate of the reaction of  $\text{Ca}^{2+}$  with  $\text{H}_2\text{O}$  at  $25^\circ\text{C}$ . The concentration of  $\text{H}_2\text{O}$  was  $55.5 \text{ mol/L}$ . The concentration of  $\text{Ca}^{2+}$  was  $0.01 \text{ mol/L}$ . The concentration of  $\text{H}_2\text{O}$  was  $55.5 \text{ mol/L}$ . The concentration of  $\text{Ca}^{2+}$  was  $0.01 \text{ mol/L}$ .

Rate	Rate	Rate	Rate
0.01	0.01	0.01	0.01
0.02	0.02	0.02	0.02
0.03	0.03	0.03	0.03
0.04	0.04	0.04	0.04
0.05	0.05	0.05	0.05
0.06	0.06	0.06	0.06
0.07	0.07	0.07	0.07
0.08	0.08	0.08	0.08
0.09	0.09	0.09	0.09
0.10	0.10	0.10	0.10
0.11	0.11	0.11	0.11
0.12	0.12	0.12	0.12
0.13	0.13	0.13	0.13
0.14	0.14	0.14	0.14
0.15	0.15	0.15	0.15
0.16	0.16	0.16	0.16
0.17	0.17	0.17	0.17
0.18	0.18	0.18	0.18
0.19	0.19	0.19	0.19
0.20	0.20	0.20	0.20
0.21	0.21	0.21	0.21
0.22	0.22	0.22	0.22
0.23	0.23	0.23	0.23
0.24	0.24	0.24	0.24
0.25	0.25	0.25	0.25
0.26	0.26	0.26	0.26
0.27	0.27	0.27	0.27
0.28	0.28	0.28	0.28
0.29	0.29	0.29	0.29
0.30	0.30	0.30	0.30
0.31	0.31	0.31	0.31
0.32	0.32	0.32	0.32
0.33	0.33	0.33	0.33
0.34	0.34	0.34	0.34
0.35	0.35	0.35	0.35
0.36	0.36	0.36	0.36
0.37	0.37	0.37	0.37
0.38	0.38	0.38	0.38
0.39	0.39	0.39	0.39
0.40	0.40	0.40	0.40
0.41	0.41	0.41	0.41
0.42	0.42	0.42	0.42
0.43	0.43	0.43	0.43
0.44	0.44	0.44	0.44
0.45	0.45	0.45	0.45
0.46	0.46	0.46	0.46
0.47	0.47	0.47	0.47
0.48	0.48	0.48	0.48
0.49	0.49	0.49	0.49
0.50	0.50	0.50	0.50
0.51	0.51	0.51	0.51
0.52	0.52	0.52	0.52
0.53	0.53	0.53	0.53
0.54	0.54	0.54	0.54
0.55	0.55	0.55	0.55
0.56	0.56	0.56	0.56
0.57	0.57	0.57	0.57
0.58	0.58	0.58	0.58
0.59	0.59	0.59	0.59
0.60	0.60	0.60	0.60
0.61	0.61	0.61	0.61
0.62	0.62	0.62	0.62
0.63	0.63	0.63	0.63
0.64	0.64	0.64	0.64
0.65	0.65	0.65	0.65
0.66	0.66	0.66	0.66
0.67	0.67	0.67	0.67
0.68	0.68	0.68	0.68
0.69	0.69	0.69	0.69
0.70	0.70	0.70	0.70
0.71	0.71	0.71	0.71
0.72	0.72	0.72	0.72
0.73	0.73	0.73	0.73
0.74	0.74	0.74	0.74
0.75	0.75	0.75	0.75
0.76	0.76	0.76	0.76
0.77	0.77	0.77	0.77
0.78	0.78	0.78	0.78
0.79	0.79	0.79	0.79
0.80	0.80	0.80	0.80
0.81	0.81	0.81	0.81
0.82	0.82	0.82	0.82
0.83	0.83	0.83	0.83
0.84	0.84	0.84	0.84
0.85	0.85	0.85	0.85
0.86	0.86	0.86	0.86
0.87	0.87	0.87	0.87
0.88	0.88	0.88	0.88
0.89	0.89	0.89	0.89
0.90	0.90	0.90	0.90
0.91	0.91	0.91	0.91
0.92	0.92	0.92	0.92
0.93	0.93	0.93	0.93
0.94	0.94	0.94	0.94
0.95	0.95	0.95	0.95
0.96	0.96	0.96	0.96
0.97	0.97	0.97	0.97
0.98	0.98	0.98	0.98
0.99	0.99	0.99	0.99

Year	Population	Area	Population
1900	1,000	100	1,000
1910	1,200	120	1,200
1920	1,500	150	1,500
1930	1,800	180	1,800
1940	2,000	200	2,000
1950	2,200	220	2,200
1960	2,500	250	2,500
1970	2,800	280	2,800
1980	3,000	300	3,000
1990	3,200	320	3,200
2000	3,500	350	3,500
2010	3,800	380	3,800
2020	4,000	400	4,000
2030	4,200	420	4,200
2040	4,500	450	4,500
2050	4,800	480	4,800
2060	5,000	500	5,000
2070	5,200	520	5,200
2080	5,500	550	5,500
2090	5,800	580	5,800
2100	6,000	600	6,000

TABLE II

Calibration of Hydraulic Scale

Inches of Mercury vs. IMEP

<u>" Hg.</u>	<u>IMEP</u>
16.7	98.0
19.3	107.6
19.8	114.8
26.3	139.2
29.5	149.6

1

01/04 1975 - 1976

1977 - 1978

1979

1980

1981

1982

1983

1984

1985

1986

1987

1988

1989

1990

1991

1992

1993

1994

1995

1996

1997

1998

1999

2000

2001

2002



# M.I.T. AERO ENGINE LABORATORY

ENGINE C F R BORE 3 1/4 STROKE 4 1/2 COMPRESSION RATIO 6.2

Table III

REMARKS	DATE	TIME	R.H.M.	TEMP.		OIL PRESS	P <sub>i</sub>	P <sub>e</sub>	T <sub>i</sub>	AIR CONS.	FUEL CONS.	F/A	S.A.	T <sub>i</sub>	FUEL ROTO	ROOM TEMP	BAR. CORR.	H <sub>2</sub> O ROTO	M <sub>w</sub>	W/F	H <sub>2</sub>	IMEP	HP	η <sub>i</sub>	15FC	15WC	15LC																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
				OIL	JAC																								4/10/46	1732	13	1200	160	212	35	30.105	ATM	543	.01011	.000646	.064	25	138	6.20	81	30.105	0	0	0	17.3	101.8	576	3265	403	0	403		"	1741	14	"	"	"	"	"	"	"	.0103	.000659	"	"	142	6.30	"	"	7.5	.000274	.416	17.85	104	588	327	403	.168	.571		"	1745	15	"	"	"	"	"	"	544	.0105	.000671	"	"	141	6.39	"	"	8.5	.000366	.545	18.55	106.8	6.04	330	399	.218	.617		"	1754	16	"	"	"	"	"	"	"	.01069	.000684	"	"	"	6.48	"	"	10.0	.000516	.755	19.35	110	6.23	3335	396	.298	.694		"	1803	17	"	"	"	"	"	"	"	.01097	.000701	"	"	"	6.62	"	"	10.5	.000570	.813	19.45	112.3	6.36	332	397	.322	.719		4/18/46	1222	1	"	"	"	33	30.375	"	546	.01095	.000767	.07	"	142	7.09	85	30.045	0	0	0	19.70	111.3	6.30	301	438	0	438		"	1401	5	"	157	"	34	30.375	"	544	.01124	.000786	"	"	141	7.23	87	"	5.6	.000335	.172	20.35	114	6.45	301	438	.075	.503		"	1425	6	"	"	"	"	30.375	"	545	.01144	.000801	"	"	140	7.34	"	"	8.7	.000385	.281	20.65	115.2	6.53	299	442	.212	.654		"	1531	7	"	"	"	"	32.375	"	"	.01168	.000817	"	"	"	7.47	"	"	10.3	.000552	.376	21.60	118.9	6.725	302	438	.246	.734		"	1540	8	"	"	"	"	30.375	"	"	.01204	.000842	"	"	138	7.63	"	"	11.8	.000701	.433	22.40	122.2	6.91	301	438	.365	.803		"	1550	9	"	"	"	"	30.645	"	"	.01232	.000862	"	"	140	7.78	"	"	13.8	.000788	.5123	23.85	127.8	7.10	307	432	.485	.917		"	1232	2	"	160	"	"	30.645	"	"	.01261	.00101	.08	"	"	8.85	85	"	0	0	0	23.00	124.5	7.045	256	.516	0	.516		"	1508	10	"	157	"	33	30.345	"	"	.01288	.001029	"	"	"	8.98	87	"	7.5	.000274	.266	23.75	127.5	7.21	257	.514	.137	.651		"	1516	11	"	"	"	"	30.875	"	"	.01310	.001048	"	"	138	9.10	"	"	11.3	.000652	.322	24.45	130.3	7.375	258	.512	.318	.830		"	1528	12	"	"	"	"	40.345	"	"	.01322	.001057	"	"	142	9.17	"	"	13.0	.000857	.812	25.20	133.3	7.55	262	.523	.408	.911		"	1540	13	"	160	"	32	40.095	"	544	.01369	.001094	"	"	138	9.38	"	"	14.4	.001052	.962	26.10	136.7	7.73	259	.510	.491	1.001		"	1549	14	"	"	"	"	39.795	"	"	.01400	.001122	"	"	140	9.55	"	"	15.7	.001244	1.108	26.85	139.8	7.91	258	.511	.567	1.078		"	1302	3	"	157	"	35	30.045	"	542	.01343	.001209	.09	"	138	10.08	83	"	0	0	0	24.75	131.4	7.44	226	.585	0	.585		"	1606	15	"	160	"	32	30.725	"	544	.01400	.001260	"	"	140	10.42	87	"	11.5	.000274	.535	26.25	137.3	7.77	226	.584	.312	.896		"	1614	16	"	"	"	"	30.045	"	"	.01384	.001247	"	"	138	10.33	"	"	9.9	.000505	.405	25.70	135.2	7.65	225	.587	.238	.825		"	1622	17	"	"	"	"	40.395	"	"	.01357	.001221	"	"	"	10.17	"	"	6.2	.000195	.152	25.15	133.1	7.53	226	.584	.089	.873		"	1632	18	"	"	"	"	30.245	"	"	.01438	.001243	"	"	140	10.63	"	"	14.0	.000997	.771	26.95	140.3	7.94	225	.587	.452	1.039		"	1639	19	"	"	"	"	39.045	"	"	.01466	.001319	"	"	138	10.78	"	"	15.5	.001245	.922	27.40	142.2	8.05	224	.590	.543	1.133		"	1320	4	"	157	"	35	"	"	542	.01389	.001389	.10	"	139	11.18	85	"	0	0	0	25.25	133.5	7.55	199	.662	0	.662		"	1655	20	"	160	"	32	30.745	"	544	.01421	.001421	"	"	138	11.38	87	"	8.7	.000384	.271	25.75	135.5	7.66	198	.668	.181	.849		"	1702	21	"	"	"	"	40.455	"	"	.01448	.001448	"	"	140	11.53	"	"	13.5	.000724	.638	26.65	139.0	7.84	199	.663	.423	1.086		"	1711	22	"	"	"	"	40.345	"	"	.01478	.001478	"	"	138	11.72	"	"	14.8	.001110	.752	27.00	140.5	7.95	195	.668	.503	1.171		"	1726	23	"	"	"	"	40.645	"	"	.01491	.001491	"	"	140	11.78	"	"	16.4	.001352	.908	27.50	142.5	8.06	198	.667	.604	1.261		"	1742
	4/10/46	1732	13	1200	160	212	35	30.105	ATM	543	.01011	.000646	.064	25	138	6.20	81	30.105	0	0	0	17.3	101.8	576	3265	403	0	403																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1741	14	"	"	"	"	"	"	"	.0103	.000659	"	"	142	6.30	"	"	7.5	.000274	.416	17.85	104	588	327	403	.168	.571																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1745	15	"	"	"	"	"	"	544	.0105	.000671	"	"	141	6.39	"	"	8.5	.000366	.545	18.55	106.8	6.04	330	399	.218	.617																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1754	16	"	"	"	"	"	"	"	.01069	.000684	"	"	"	6.48	"	"	10.0	.000516	.755	19.35	110	6.23	3335	396	.298	.694																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1803	17	"	"	"	"	"	"	"	.01097	.000701	"	"	"	6.62	"	"	10.5	.000570	.813	19.45	112.3	6.36	332	397	.322	.719																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	4/18/46	1222	1	"	"	"	33	30.375	"	546	.01095	.000767	.07	"	142	7.09	85	30.045	0	0	0	19.70	111.3	6.30	301	438	0	438																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1401	5	"	157	"	34	30.375	"	544	.01124	.000786	"	"	141	7.23	87	"	5.6	.000335	.172	20.35	114	6.45	301	438	.075	.503																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1425	6	"	"	"	"	30.375	"	545	.01144	.000801	"	"	140	7.34	"	"	8.7	.000385	.281	20.65	115.2	6.53	299	442	.212	.654																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1531	7	"	"	"	"	32.375	"	"	.01168	.000817	"	"	"	7.47	"	"	10.3	.000552	.376	21.60	118.9	6.725	302	438	.246	.734																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1540	8	"	"	"	"	30.375	"	"	.01204	.000842	"	"	138	7.63	"	"	11.8	.000701	.433	22.40	122.2	6.91	301	438	.365	.803																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1550	9	"	"	"	"	30.645	"	"	.01232	.000862	"	"	140	7.78	"	"	13.8	.000788	.5123	23.85	127.8	7.10	307	432	.485	.917																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1232	2	"	160	"	"	30.645	"	"	.01261	.00101	.08	"	"	8.85	85	"	0	0	0	23.00	124.5	7.045	256	.516	0	.516																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1508	10	"	157	"	33	30.345	"	"	.01288	.001029	"	"	"	8.98	87	"	7.5	.000274	.266	23.75	127.5	7.21	257	.514	.137	.651																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1516	11	"	"	"	"	30.875	"	"	.01310	.001048	"	"	138	9.10	"	"	11.3	.000652	.322	24.45	130.3	7.375	258	.512	.318	.830																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1528	12	"	"	"	"	40.345	"	"	.01322	.001057	"	"	142	9.17	"	"	13.0	.000857	.812	25.20	133.3	7.55	262	.523	.408	.911																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1540	13	"	160	"	32	40.095	"	544	.01369	.001094	"	"	138	9.38	"	"	14.4	.001052	.962	26.10	136.7	7.73	259	.510	.491	1.001																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1549	14	"	"	"	"	39.795	"	"	.01400	.001122	"	"	140	9.55	"	"	15.7	.001244	1.108	26.85	139.8	7.91	258	.511	.567	1.078																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1302	3	"	157	"	35	30.045	"	542	.01343	.001209	.09	"	138	10.08	83	"	0	0	0	24.75	131.4	7.44	226	.585	0	.585																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1606	15	"	160	"	32	30.725	"	544	.01400	.001260	"	"	140	10.42	87	"	11.5	.000274	.535	26.25	137.3	7.77	226	.584	.312	.896																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1614	16	"	"	"	"	30.045	"	"	.01384	.001247	"	"	138	10.33	"	"	9.9	.000505	.405	25.70	135.2	7.65	225	.587	.238	.825																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1622	17	"	"	"	"	40.395	"	"	.01357	.001221	"	"	"	10.17	"	"	6.2	.000195	.152	25.15	133.1	7.53	226	.584	.089	.873																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1632	18	"	"	"	"	30.245	"	"	.01438	.001243	"	"	140	10.63	"	"	14.0	.000997	.771	26.95	140.3	7.94	225	.587	.452	1.039																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1639	19	"	"	"	"	39.045	"	"	.01466	.001319	"	"	138	10.78	"	"	15.5	.001245	.922	27.40	142.2	8.05	224	.590	.543	1.133																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1320	4	"	157	"	35	"	"	542	.01389	.001389	.10	"	139	11.18	85	"	0	0	0	25.25	133.5	7.55	199	.662	0	.662																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1655	20	"	160	"	32	30.745	"	544	.01421	.001421	"	"	138	11.38	87	"	8.7	.000384	.271	25.75	135.5	7.66	198	.668	.181	.849																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1702	21	"	"	"	"	40.455	"	"	.01448	.001448	"	"	140	11.53	"	"	13.5	.000724	.638	26.65	139.0	7.84	199	.663	.423	1.086																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1711	22	"	"	"	"	40.345	"	"	.01478	.001478	"	"	138	11.72	"	"	14.8	.001110	.752	27.00	140.5	7.95	195	.668	.503	1.171																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1726	23	"	"	"	"	40.645	"	"	.01491	.001491	"	"	140	11.78	"	"	16.4	.001352	.908	27.50	142.5	8.06	198	.667	.604	1.261																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	"	1742	24	"	"	"	"	40.845	"	"	.01524	.001719	.064	"	"	6.74	86	"	12.0	.000725	1.028	28.5	114.7	6.49	331	.398	.462	.800																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														



# M.I.T. AERO ENGINE LABORATORY

ENGINE *CFH* BORE  $3\frac{1}{4}$  STROKE  $4\frac{1}{2}$  COMPRESSION RATIO 6.6

Table IV

REMARKS	DATE	TIME	RPM	TEMPERATURE OIL	JAC	OIL PRES	P <sub>i</sub>	P <sub>E</sub>	T	AIR CONS.	FUEL CONS.	F A	S.A.	T <sub>i</sub>	FUEL Roto	ROOM TEMP	BAR. CORR.	H <sub>2</sub> O Roto	M <sub>w</sub>	W/F	"H <sub>g</sub>	IMEP	IHP	η <sub>i</sub>	ISFC	ISWC	ISLC
	4/24/44	1304	1	158	212	53	37.84	47M	542	.01267	.001267	.10	2.5	140	10.45	81	30.144	0	0	0	22.9	124	7.02	2035	.650	0	.650
		1310	2	"	"	"	37.54	"	544	.01280	.001280	"	"	138	10.54	"	"	9.3	.000446	3.49	23.25	125.5	7.10	2035	.649	.226	.875
		1320	3	"	"	"	37.24	"	"	.01291	.001291	"	"	140	10.61	"	"	11.9	.000713	5.53	33.45	126.3	7.14	203	.651	.360	1.011
		1330	4	"	"	"	36.94	"	"	.01310	.001310	"	"	"	10.73	80	"	13.4	.000912	6.96	33.8	127.7	7.22	202	.653	.455	1.108
		1331	5	"	"	"	36.44	"	"	.01330	.001330	"	"	"	10.84	79	"	14.5	.001067	8.02	34.15	129.2	7.32	202	.654	.525	1.179
		1355	6	"	"	"	38.64	"	545	.01234	.001111	.09	"	"	9.50	78	"	0	0	0	22.35	121.8	6.89	228	.581	0	.581
		1402	7	"	"	"	38.24	"	"	.01248	.001122	"	"	"	9.55	77	"	7.4	.000264	2.35	22.65	123.0	6.96	228	.581	.136	.717
		1414	8	"	"	"	38.04	"	"	.01268	.001139	"	"	138	9.65	"	"	9.6	.000477	4.19	23.3	125.6	7.10	229	.578	.242	.820
		1423	9	156	"	34	37.54	"	"	.01280	.001152	"	"	"	9.73	78	"	11.0	.00062	5.38	23.8	127.7	7.22	230	.575	.309	.884
		1431	10	"	"	"	37.04	"	"	.01306	.001175	"	"	140	9.88	80	"	12.9	.000843	7.17	34.3	129.7	7.33	229	.577	.414	.941
		1438	11	"	"	"	36.74	"	"	.01320	.001188	"	"	"	9.96	"	"	14.4	.001052	8.86	34.95	132.2	7.42	231	.572	.507	1.079
		1450	12	"	"	"	46.34	"	"	.01152	.000720	.08	"	142	8.2	81	"	0	0	0	20.4	116.2	6.675	266	.497	0	.497
		1458	13	"	"	"	39.84	"	"	.01173	.000733	"	"	140	8.29	"	"	7.0	.000238	2.45	21.6	118.9	6.725	264	.500	.122	.622
		1514	14	"	"	"	39.44	"	546	.01197	.000756	"	"	"	8.46	"	"	8.4	.000555	3.71	22.0	120.5	6.82	262	.505	.187	.692
		1523	15	"	"	"	38.94	"	"	.01233	.000778	"	"	142	8.62	"	"	12.5	.000792	8.1	22.85	123.9	7.00	262	.503	.407	.910
		1531	16	"	"	"	38.44	"	"	.01249	.000798	"	"	140	8.77	"	"	14.0	.000998	10.0	23.7	127.2	7.20	264	.449	.449	.898
		1541	17	"	"	"	39.14	"	"	.01212	.000769	"	"	"	8.55	"	"	10.2	.000546	5.57	22.55	123.6	6.94	262	.502	.280	.782
		1548	18	"	"	"	38.94	"	"	.01008	.000705	.07	"	"	6.65	"	"	0	0	0	17.55	102.8	5.82	303	.437	0	.437
		1613	19	"	"	"	38.24	"	547	.01032	.000721	"	"	"	6.75	"	"	7.0	.000228	3.16	18.3	105.7	5.975	304	.434	.137	.571
		1619	20	"	"	"	37.54	"	"	.01054	.000739	"	"	139	6.88	"	"	10.1	.000530	7.17	18.95	108.5	6.14	305	.433	.311	.714
		1628	21	"	"	"	36.74	"	"	.01087	.000760	"	"	140	7.04	82	"	11.5	.000674	8.87	19.5	110.5	6.25	303	.428	.388	.826
		1637	22	"	"	"	37.84	"	"	.01049	.000730	"	"	"	6.83	"	"	8.2	.000337	4.61	19.55	106.8	6.04	303	.405	.201	.634
		1710	23	"	"	"	37.24	"	548	.00881	.000565	.064	"	"	5.57	83	"	0	0	0	14.65	91.1	5.16	335	.394	0	.394
		1720	24	"	"	"	36.34	"	"	.00902	.000577	"	"	"	5.67	"	"	5.4	.000118	2.05	15.3	93.6	5.30	337	.392	.0802	.472
		1726	25	"	"	"	35.64	"	"	.00917	.000587	"	"	"	5.74	"	"	7.6	.000383	4.82	15.9	96.0	5.43	340	.390	.188	.578
		1732	26	"	"	"	34.84	"	"	.00937	.000600	"	"	"	5.84	"	"	8.5	.000367	6.12	16.1	97.0	5.49	336	.393	.241	.634
		1742	27	"	"	"	33.94	"	"	.00956	.000612	"	"	"	5.93	"	"	10.1	.00053	8.66	16.6	99.0	5.60	336	.393	.341	.734



# M.I.T. AERO ENGINE LABORATORY

ENGINE *CFR* BORE  $3\frac{1}{4}$  STROKE  $4\frac{1}{2}$  COMPRESSION RATIO 7.0

Table V

REMARKS	DRIE TIME	RPM	TEMP. OIL	TEMP. JAC	OIL PRESS	P <sub>i</sub>	P <sub>e</sub>	T <sub>i</sub>	AIR CONS.	FUEL CONS.	F/A	S.A.	T <sub>i</sub>	Fuel Roto	Room TEMP	BAR. CORR.	H <sub>2</sub> O Roto	M <sub>w</sub>	W/F	" H <sub>g</sub>	IMEP	IHP	η <sub>i</sub>	ISFC	ISWC	ISLC
	4/23/46	1440	160	212	24	30.539	ATM	545	.00801	.000514	.064	25	140	5.15	87	"	0	0	0	13.5	84.4	4.77	340	.388	0	.388
	"	1452	"	157	32	34.104	"	"	.00838	.000536	"	"	"	5.33	"	"	6.7	.000213	.397	13.9	88.0	4.98	341	.387	.154	.541
	"	1457	158	"	33	38.209	"	"	.00866	.000554	"	"	"	5.48	"	"	8.1	.000327	.591	14.3	89.6	5.07	335	.393	.232	.625
	"	1507	"	"	"	38.304	"	"	.00905	.000574	"	"	"	5.69	88	"	9.8	.000496	.873	15.3	93.6	5.30	335.5	.393	.337	.730
	"	1518	"	"	"	37.204	"	"	.00934	.000598	"	"	"	5.83	"	"	11.8	.000698	1.168	16.1	96.8	5.48	336	.393	.458	.851
	"	1527	"	"	"	32.604	"	546	.00950	.000608	"	"	"	5.92	"	"	12.6	.000805	1.322	16.32	97.7	5.53	333.5	.396	.523	.919
	"	1536	"	"	"	"	"	"	.00946	.000660	.07	"	"	6.31	"	"	0	0	0	16.0	96.6	5.47	304	.435	0	.435
	"	1545	"	"	"	32.204	"	"	.00968	.000677	"	"	"	6.41	"	"	8.2	.000336	.496	16.8	99.8	5.65	306	.432	.214	.646
	"	1555	"	"	"	32.404	"	"	.00991	.000694	"	"	"	6.56	"	"	9.5	.000465	.671	17.4	102.1	5.78	305	.432	.290	.722
	"	1604	"	"	"	36.504	"	"	.01013	.000709	"	"	"	6.68	"	"	10.8	.000600	.847	17.9	104.2	5.90	305	.433	.366	.799
	4/24/46	1334	"	"	32	34.923	"	543	.01054	.000738	"	"	"	6.88	83	"	13.3	.000900	1.220	19.5	110.4	6.25	310	.425	.519	.944
	"	1401	"	"	34	37.563	"	545	.01029	.000720	"	"	"	6.75	88	"	11.8	.000702	.975	18.7	107.3	6.075	309.6	.427	.416	.843
	4/23/46	1625	"	"	33	30.409	"	547	.01079	.000862	.08	"	"	7.78	"	"	0	0	0	19.2	109.4	6.195	259	.509	0	.509
	4/24/46	1423	"	"	35	34.573	"	546	.01097	.000877	"	"	"	7.89	"	"	9.6	.000477	.544	20.0	112.5	6.36	266	.496	.270	.766
	"	1430	"	"	"	32.263	"	"	.01118	.000893	"	"	"	8.0	"	"	11.0	.000418	.692	20.75	115.6	6.54	268	.492	.340	.832
	"	1435	"	"	"	34.763	"	"	.01133	.000907	"	"	"	8.1	"	"	12.2	.000794	.931	21.0	116.7	6.60	267	.495	.412	.907
	"	1442	"	"	34	31.813	"	"	.01140	.000911	"	"	"	8.13	"	"	13.0	.000857	.940	21.3	117.8	6.66	268	.492	.463	.955
	"	1452	"	"	"	34.263	"	"	.01182	.000945	"	"	"	8.38	"	"	14.7	.001098	1.160	22.3	121.7	6.88	267	.495	.575	1.070
	"	1615	"	"	"	30.363	"	"	.01147	.001027	.14	"	"	8.97	86	"	0	0	0	20.8	115.8	6.55	234	.565	0	.565
	"	1623	"	155	35	30.063	"	"	.01162	.001046	"	"	"	9.08	85	"	6.9	.000222	.211	21.1	117.4	6.62	232	.568	.196	.688
	"	1653	"	"	"	32.563	"	"	.01191	.001072	"	"	"	9.24	84	"	13.5	.000724	.862	22.5	122.5	6.93	237	.557	.480	1.017
	"	1708	"	"	"	39.063	"	"	.01181	.001063	"	"	"	9.18	"	"	10.3	.000532	.519	21.4	120.0	6.74	234	.564	.242	.856
	"	1717	"	"	"	34.463	"	"	.01206	.001084	"	"	"	9.32	"	"	15.0	.00114	1.052	22.7	123.3	6.98	230	.560	.588	1.148
	"	1730	"	"	"	34.963	"	"	.01218	.001094	"	"	"	9.38	"	"	12.0	.000442	1.318	22.9	124.2	7.03	236	.561	.739	1.300
	4/25/46	1228	"	160	31	41.75	"	547	.01175	.001175	.10	"	138	9.89	87	"	0	0	0	20.75	115.6	6.54	204	.635	0	.635
	"	1240	"	"	32	41.55	"	"	.01188	.001188	"	"	140	9.96	"	"	8.3	.000347	.292	21.1	117.0	6.42	204	.646	.189	.835
	"	1250	"	"	"	41.15	"	"	.01211	.001211	"	"	142	10.1	"	"	13.0	.000858	.708	21.7	119.3	6.75	204.5	.646	.458	1.104
	"	1300	"	"	"	41.35	"	"	.01248	.001248	"	"	140	10.34	"	"	16.3	.001334	1.608	22.4	122.1	6.91	203	.650	.496	1.346
	"	1312	"	"	33	41.25	"	"	.01200	.001200	"	"	138	10.04	"	"	12.1	.00053	.710	21.7	118.1	6.68	204	.647	.286	.933



# M.I.T. AERO ENGINE LABORATORY

ENGINE CFR

BORE 3 1/4 STROKE 4 1/2 COMPRESSION RATIO 7.4

Table VI

REMARKS	DATE	TIME	RPM	TEMPERATURE		OIL PRES.	P <sub>i</sub>	P <sub>e</sub>	T <sub>i</sub>	AIR CONS.	FUEL CONS.	F/A	S. A.	T <sub>i</sub>	FUEL RSTO	Room TEMP.	BAR. CORR.	H <sub>2</sub> O RSTO	M <sub>W</sub>	W/F	"Hg	IMEP	IHP	η <sub>i</sub>	ISFC	ISWC	ISLG
				OIL	JAC																						
4/25/46	1337	6	1200	160	33	40.25	ATM	547	.01072	.001072	.10	.25	140	9.25	89	29.85	0	0	0	18.75	107.5	6.08	.208	.635	0	.635	
"	"	1347	7	158	"	40.15	"	"	"	.01088	.001088	"	"	"	9.35	"	"	6.3	.00192	.176	18.85	108.0	6.12	.2063	.640	.113	.753
"	"	1353	8	"	"	40.05	"	"	"	.01108	.001108	"	"	138	9.47	"	"	9.0	.000413	.373	19.15	109.1	6.175	.2045	.646	.241	.887
"	"	1401	9	"	"	39.65	"	"	"	.01133	.001133	"	"	"	9.63	"	"	12.9	.000844	.745	19.9	112.2	6.295	.204	.648	.483	.151
"	"	1410	10	"	"	39.45	"	"	"	.01153	.001153	"	"	140	9.74	"	"	14.4	.001052	.913	20.35	114.0	6.455	.205	.644	.588	.1232
"	"	1425	11	"	"	40.95	"	"	"	.01064	.000960	.09	"	"	8.49	"	"	0	0	0	18.8	107.7	6.09	.233	.567	0	.567
"	"	1435	12	"	"	40.75	"	"	"	.01080	.000972	"	"	"	8.57	"	"	7.6	.000283	.291	19.3	109.7	6.21	.234	.564	.164	.728
"	"	1442	13	"	"	40.45	"	"	"	.01102	.000991	"	"	"	8.72	88	"	10.4	.000562	.567	19	111.1	6.29	.233	.567	.322	.889
"	"	1452	14	"	"	40.25	"	"	"	.01132	.001016	"	"	138	8.92	"	"	14.1	.00101	.994	20.6	115	6.51	.235	.562	.559	.1121
"	"	1458	15	"	"	39.65	"	"	"	.01156	.001040	"	"	"	9.05	"	"	17.5	.001534	1.465	21.3	117.7	6.66	.2345	.562	.824	.1386
"	"	1520	16	"	"	40.65	"	"	"	.00953	.000762	.08	"	142	7.05	"	"	0	0	0	16.6	99.1	5.61	.270	.489	0	.489
"	"	1531	17	"	"	40.15	"	"	"	.00981	.000785	"	"	140	7.23	"	"	7.3	.000242	.309	17	100.6	5.69	.266	.497	.153	.650
"	"	1540	18	"	"	39.85	"	"	"	.01000	.000800	"	"	"	7.34	"	"	9.1	.000424	.531	17.55	102.8	5.82	.266	.495	.262	.757
"	"	1555	19	"	"	39.55	"	"	"	.01041	.000833	"	"	"	7.58	"	"	11.2	.000440	.769	19.45	106.3	6.02	.265	.498	.383	.881
"	"	1608	20	"	"	38.55	"	"	"	.01066	.000852	"	"	"	7.72	87	"	13.5	.000925	1.086	19.65	111.2	6.295	.271	.488	.529	.1017
"	"	1618	21	"	"	38.15	"	"	"	.01089	.000871	"	"	138	7.84	"	"	14.3	.00104	1.194	20.1	113	6.40	.269	.490	.585	.1075
"	"	1640	22	"	"	29.85	"	548	.00812	.000568	.07	"	"	"	5.60	"	"	0	0	0	13.1	85	4.815	.311	.425	0	.425
"	"	1647	23	"	"	"	"	"	"	.00833	.000583	"	"	142	5.72	"	"	5.6	.00135	.232	13.6	87	4.925	.310	.427	.0987	.526
"	"	1655	24	"	"	"	"	"	"	.00852	.000596	"	"	"	5.81	"	"	9.3	.000348	.544	14.25	89.5	5.07	.312	.423	.247	.670
"	"	1659	25	"	"	"	"	"	"	.00885	.000619	"	"	140	5.99	"	"	10.3	.000550	.889	14.9	92	5.21	.3085	.428	.380	.868
"	"	1707	26	"	"	"	"	"	"	.00912	.000638	"	"	"	6.13	88	"	12.5	.000793	1.242	15.45	94.3	5.34	.307	.430	.535	.965
"	"	1716	27	"	"	"	"	549	.00693	.000443	.064	"	"	142	4.49	89	"	0	0	0	16	72.7	4.112	.340	.388	0	.388
"	"	1724	28	"	"	"	"	"	"	.00709	.000454	"	"	143	4.59	"	"	5.2	.000102	.225	16.55	74.8	4.23	.342	.386	.0867	.473
"	"	1732	29	"	"	"	"	"	"	.00727	.000465	"	"	"	4.69	"	"	7.3	.000255	.549	11.1	77.0	4.36	.344	.384	.211	.595
"	"	1741	30	"	"	"	"	"	"	.00756	.000484	"	"	140	4.87	"	"	9.0	.000413	.854	11.75	79.5	4.50	.341	.387	.331	.718
"	"	1748	31	"	"	"	"	"	"	.00784	.000502	"	"	"	5.04	"	"	10.4	.000560	1.116	12.1	81	4.58	.335	.394	.439	.833
9/2/46	1212	1	"	156	"	36.78	"	550	.01026	.001174	.11	"	"	10	87	21.87	0	0	0	18.8	107	6.05	.186	.711	0	.711	
"	"	1225	2	"	"	38.28	"	"	"	.01066	.001191	.12	"	"	8.86	"	"	"	"	"	18.7	107.3	6.07	.220	.000	"	.000
"	"	1235	3	"	"	31.18	"	"	"	.01021	.000711	.085	"	"	7.85	"	"	"	"	"	17.7	123.7	5.85	.246	.532	"	.532
"	"	1250	4	"	"	40.07	"	"	"	.01083	.000661	.115	"	"	6.38	"	"	"	"	"	14.8	91.7	5.18	.287	.700	"	.700





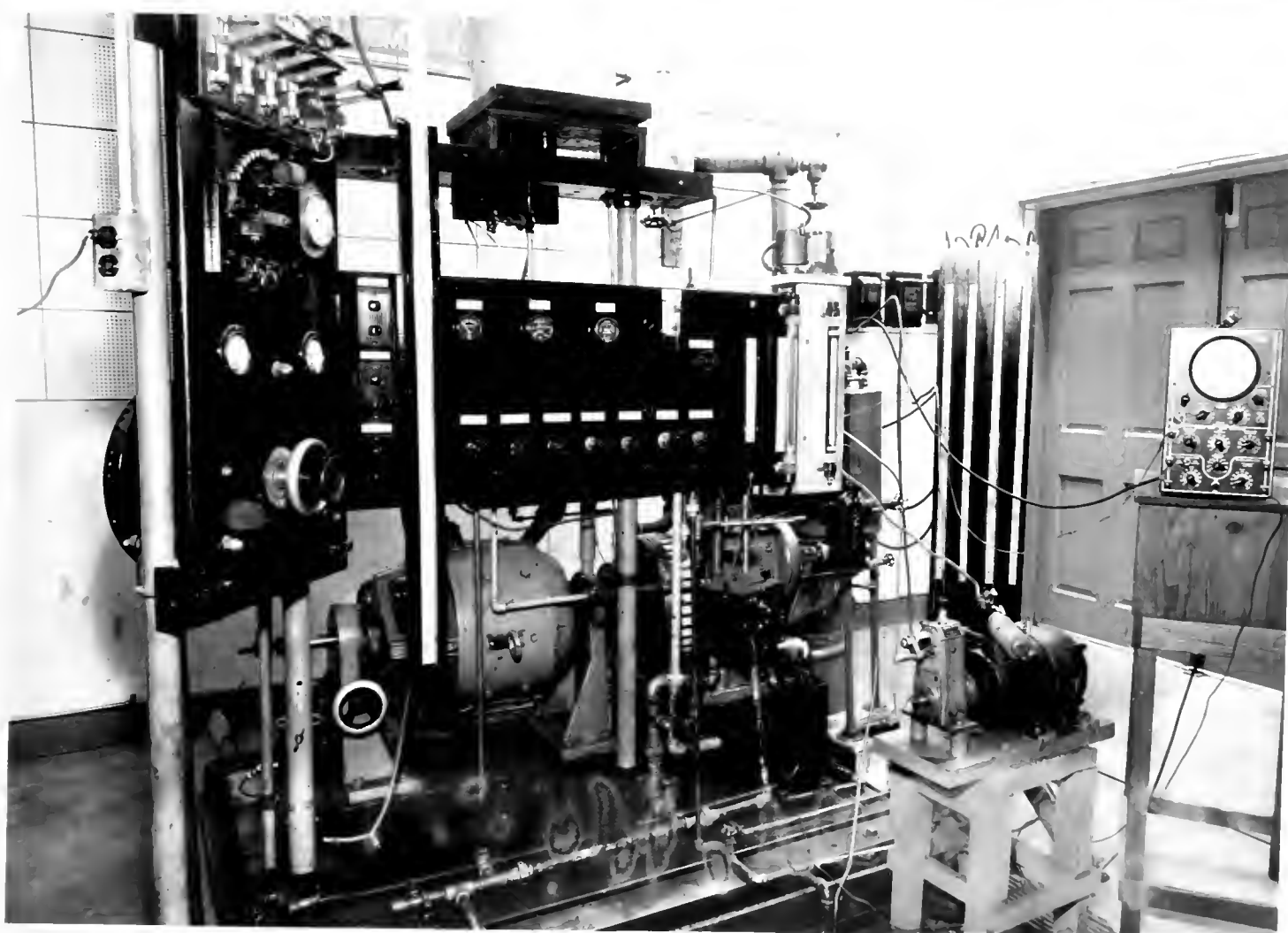


FIG. 1.  
FRONT VIEW SHOWING GENERAL ARRANGEMENT  
OF APPARATUS

100-100000

100-100000

FIG. 1.  
FRONT VIEW OF THE GENERAL ARRANGEMENT  
OF THE APPARATUS

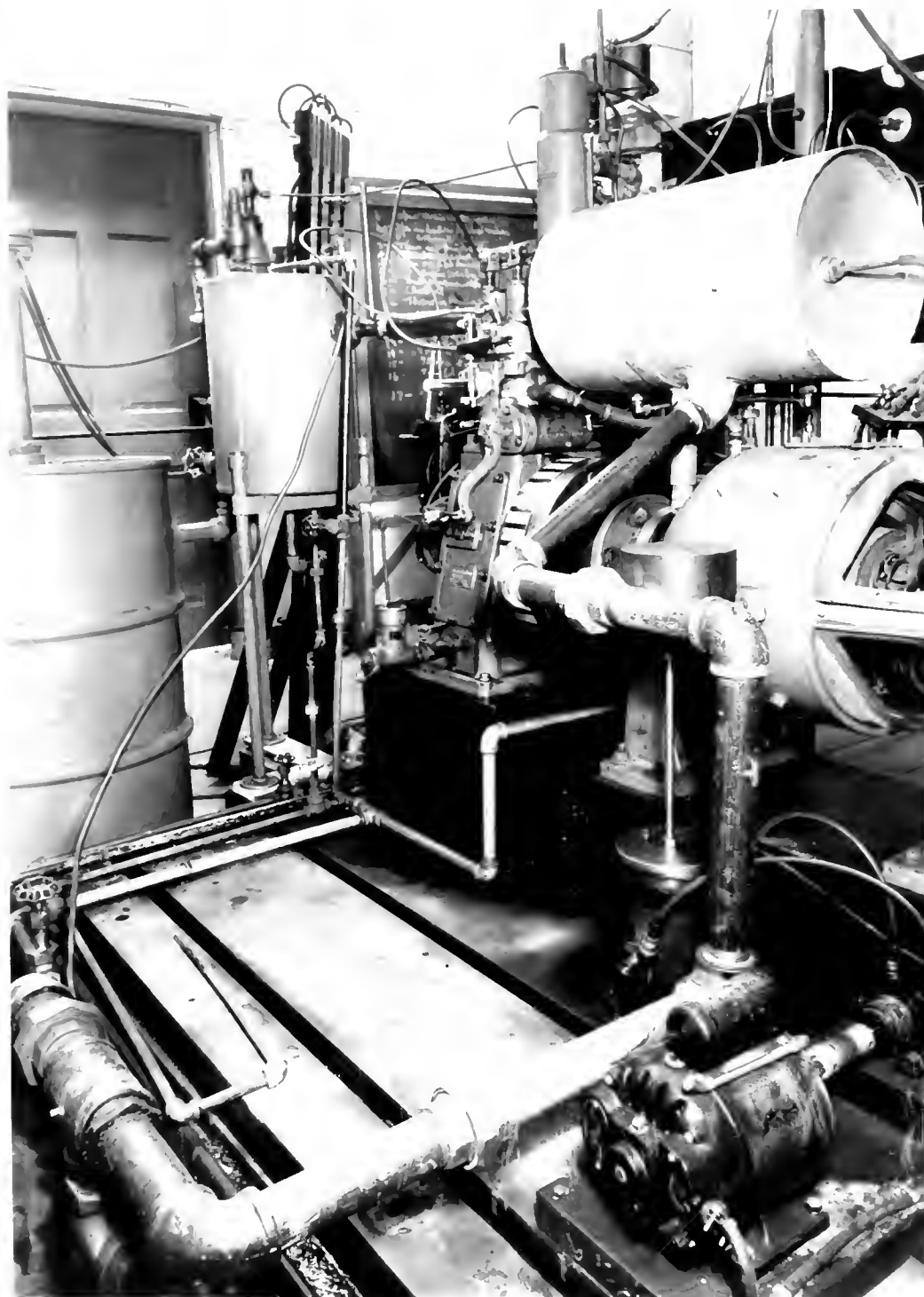


FIG. 2.  
REAR VIEW SHOWING GENERAL ARRANGEMENT  
OF APPARATUS

11.11.11

2

11.11.11

11.11.11

11.11.11  
11.11.11  
11.11.11

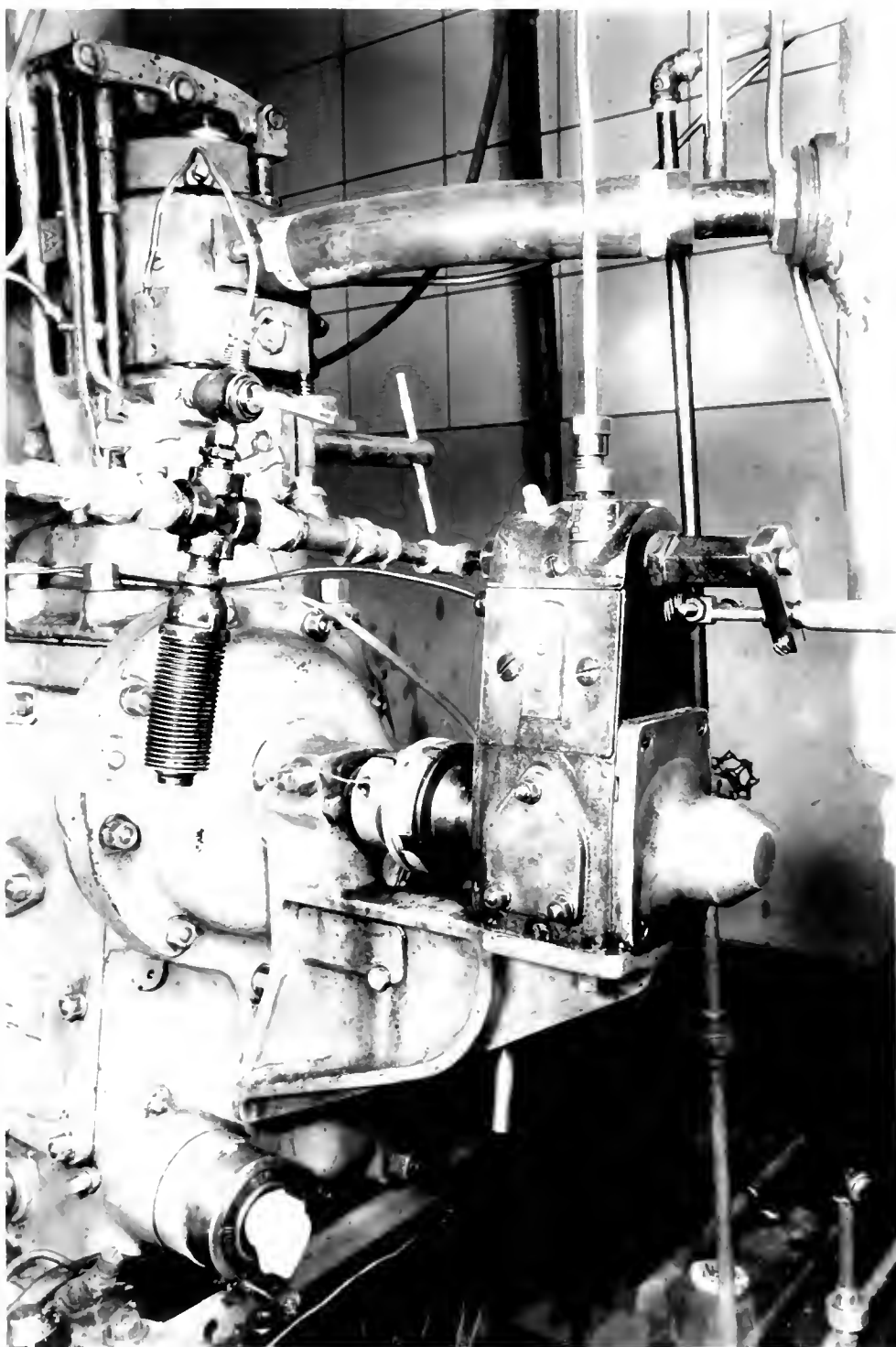


FIG. 3.

BOSCH PUMP USED FOR WATER INJECTION

FIG. 3.  
BOSSON PUMP USED FOR WATER LIFTING

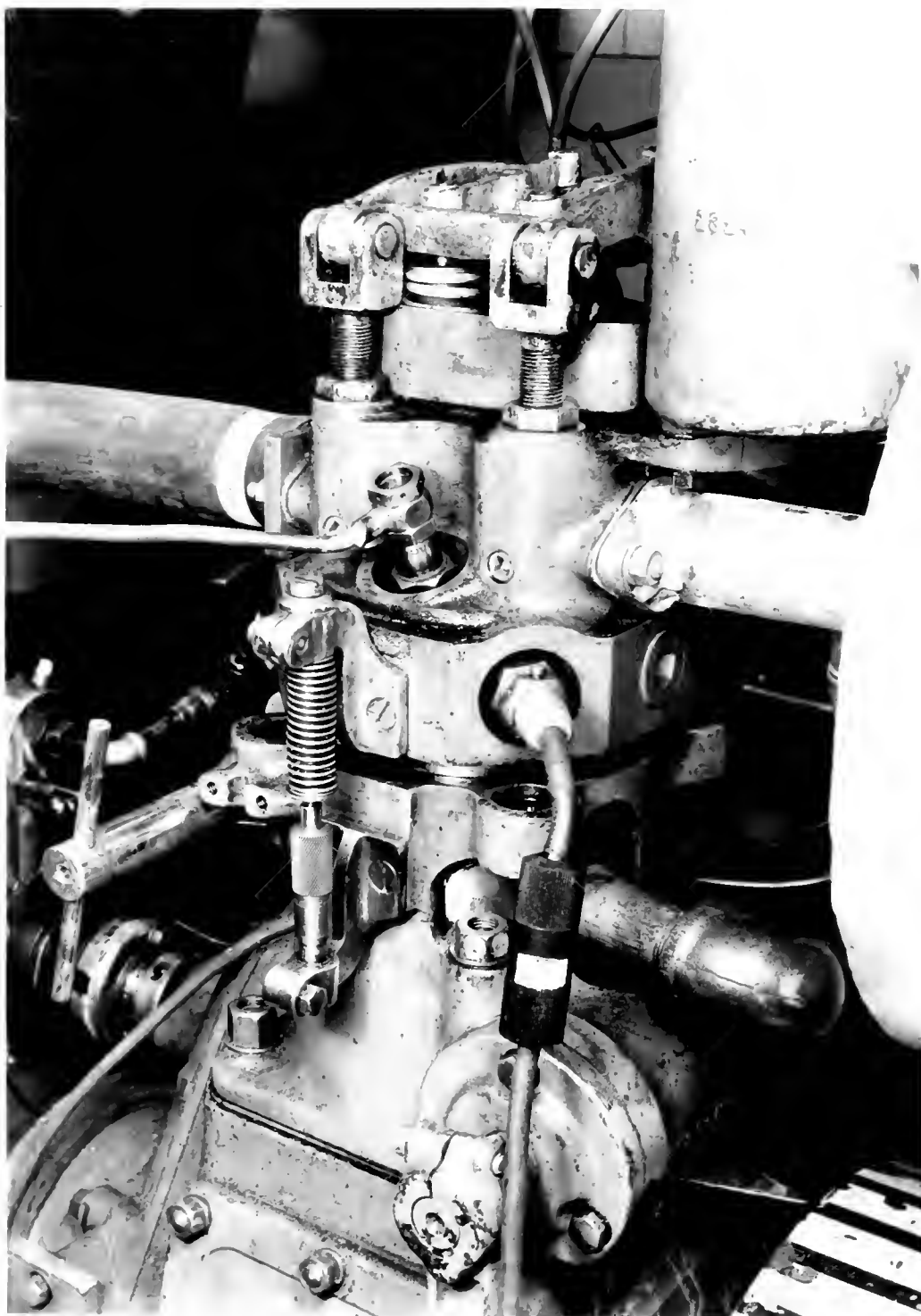


FIG. 4.

LOCATION OF WATER INJECTION NOZZLE  
AND COMPRESSION RATIO ADJUSTMENT

Fig. 4.

LOCATION OF WATER INJECTION NOZZLES  
AND OF INJECTION WATER ADJUSTMENT



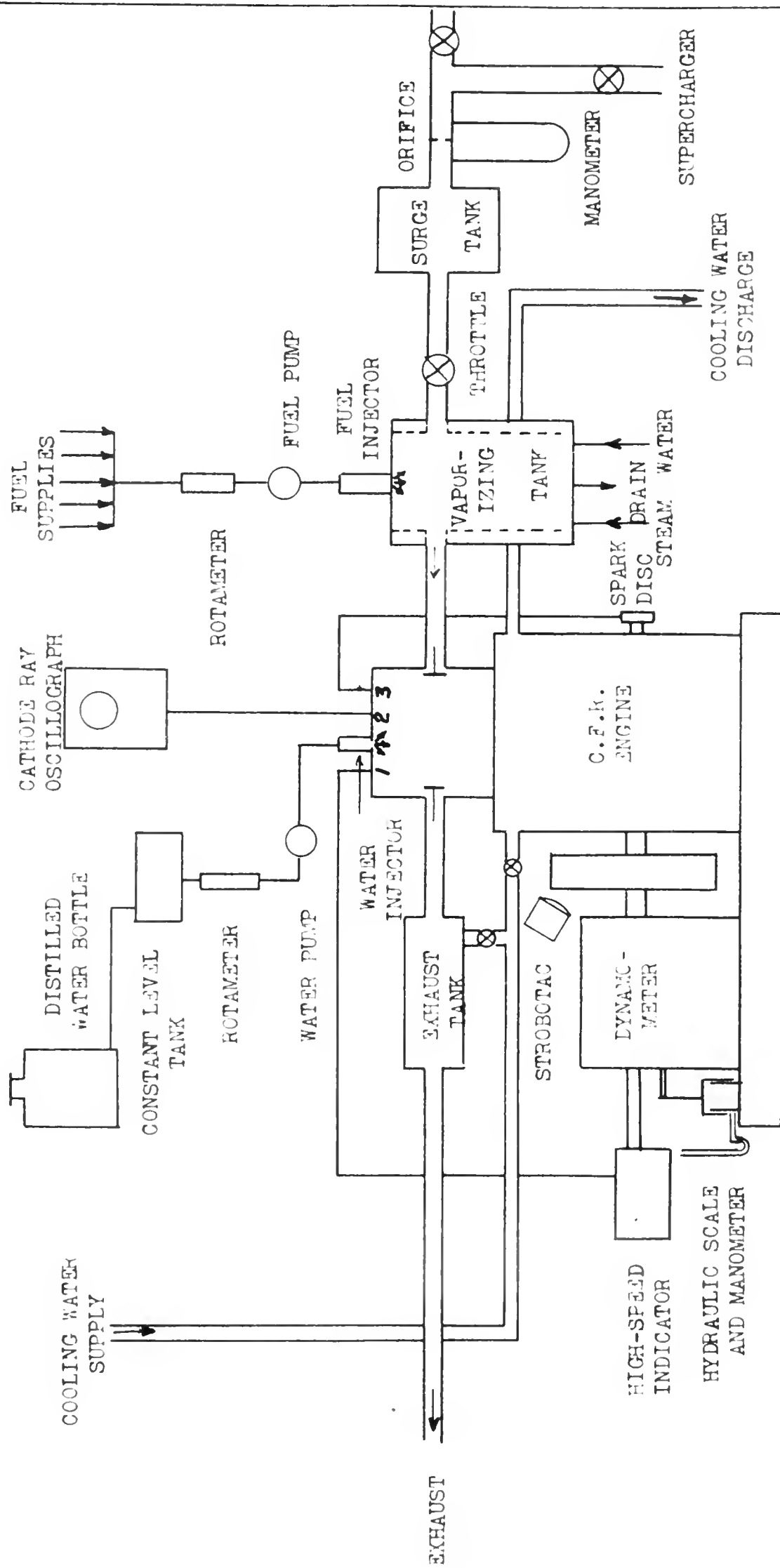


Fig. 5.

1. INDICATOR PICKUP
2. RATE OF PRESSURE PICKUP
3. SPARK PLUG

SLOAN LABORATORY  
EXPERIMENTAL C.F.R. ENGINE SETUP



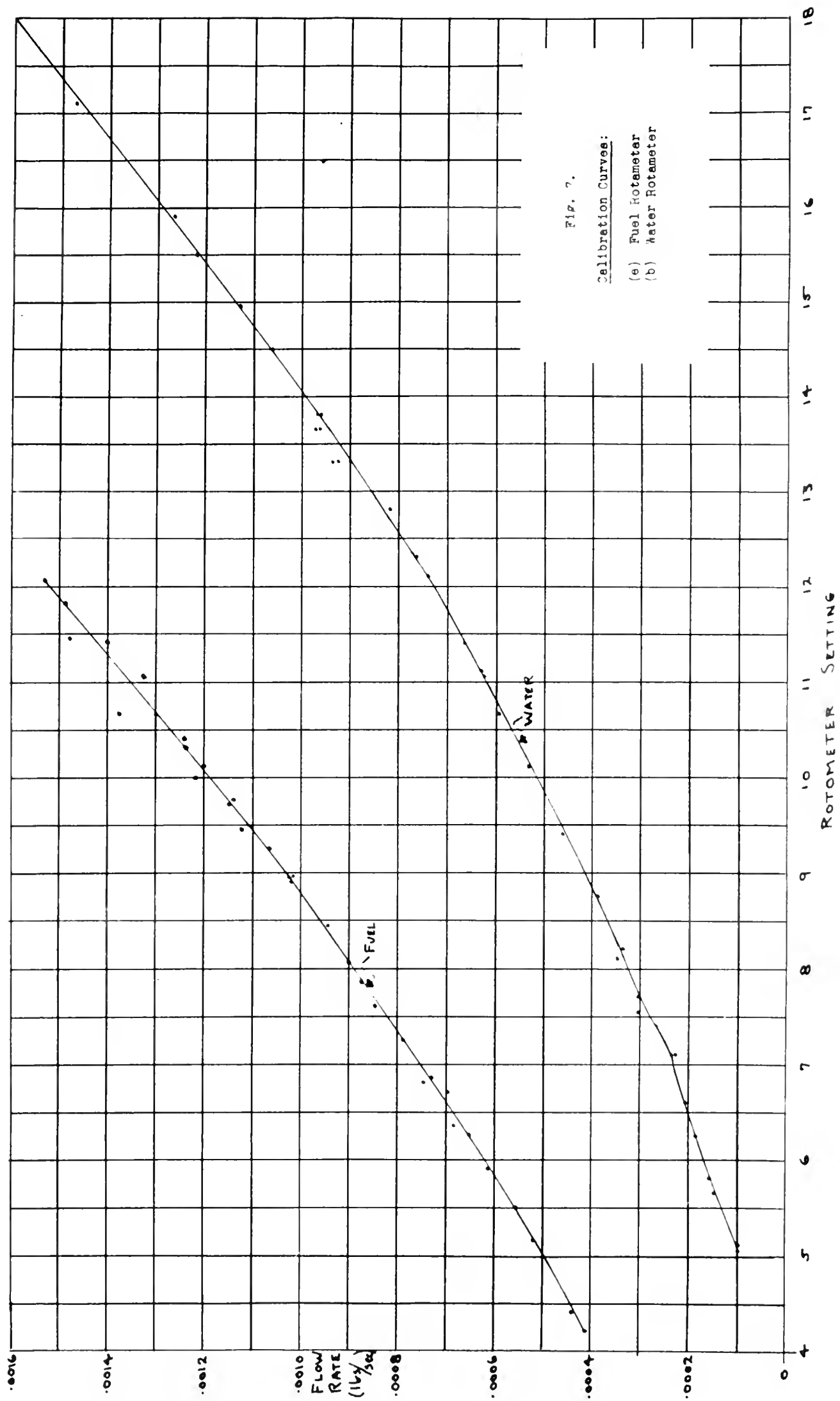


FIG. 6.

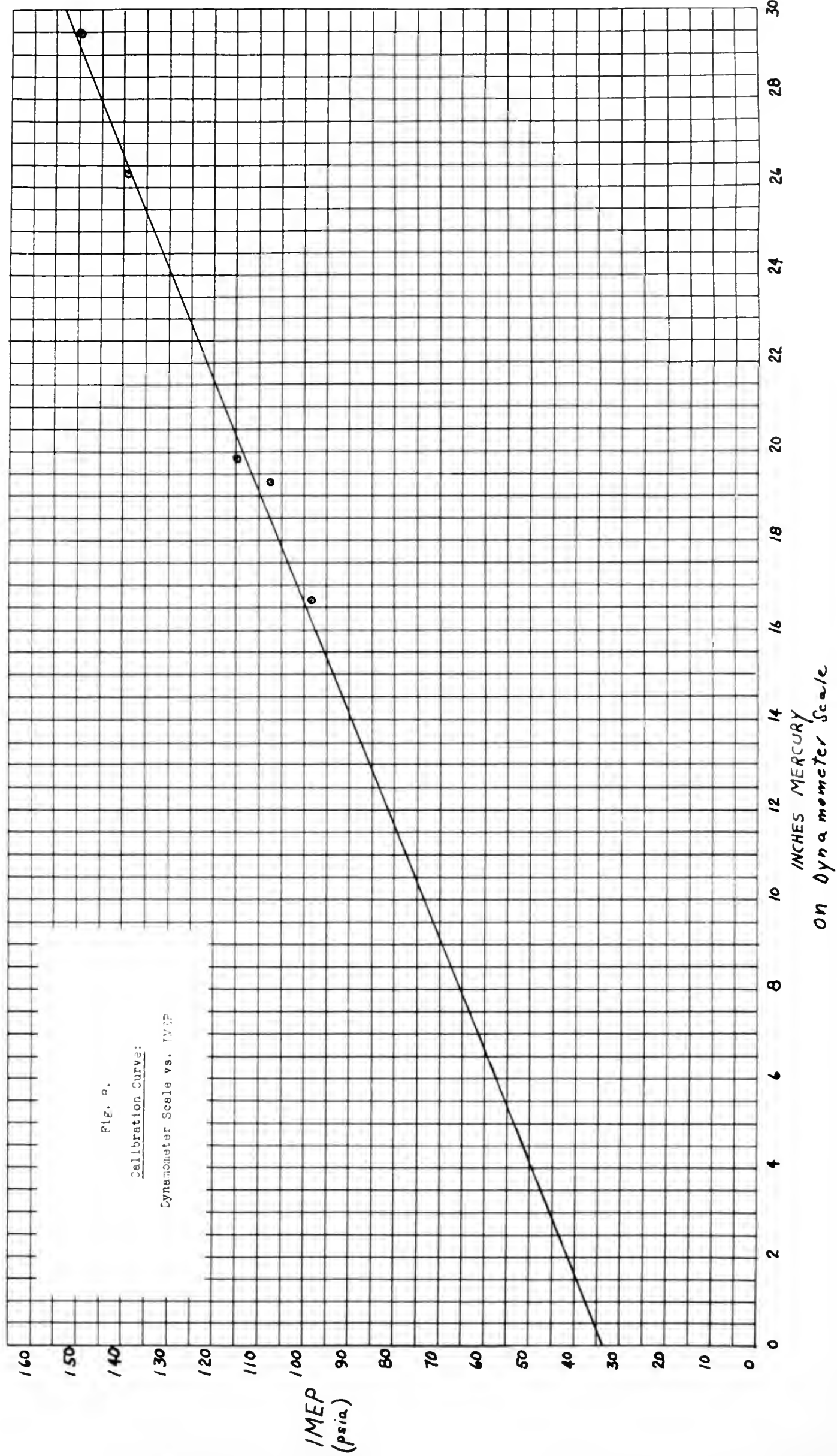
EXHIBIT NO 5081 MEXICO USED

FOR THE INVESTIGATION OF THE CASE

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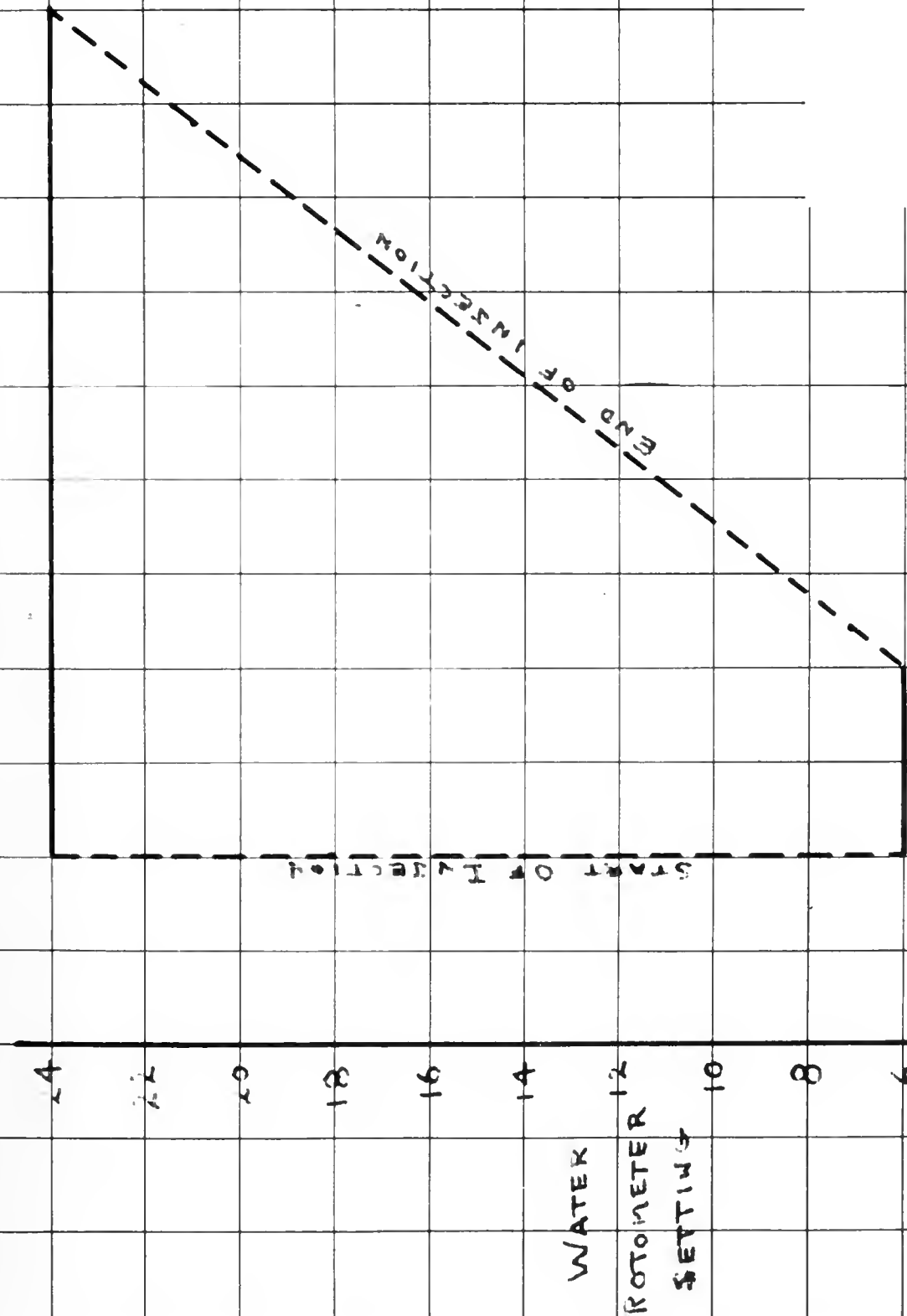
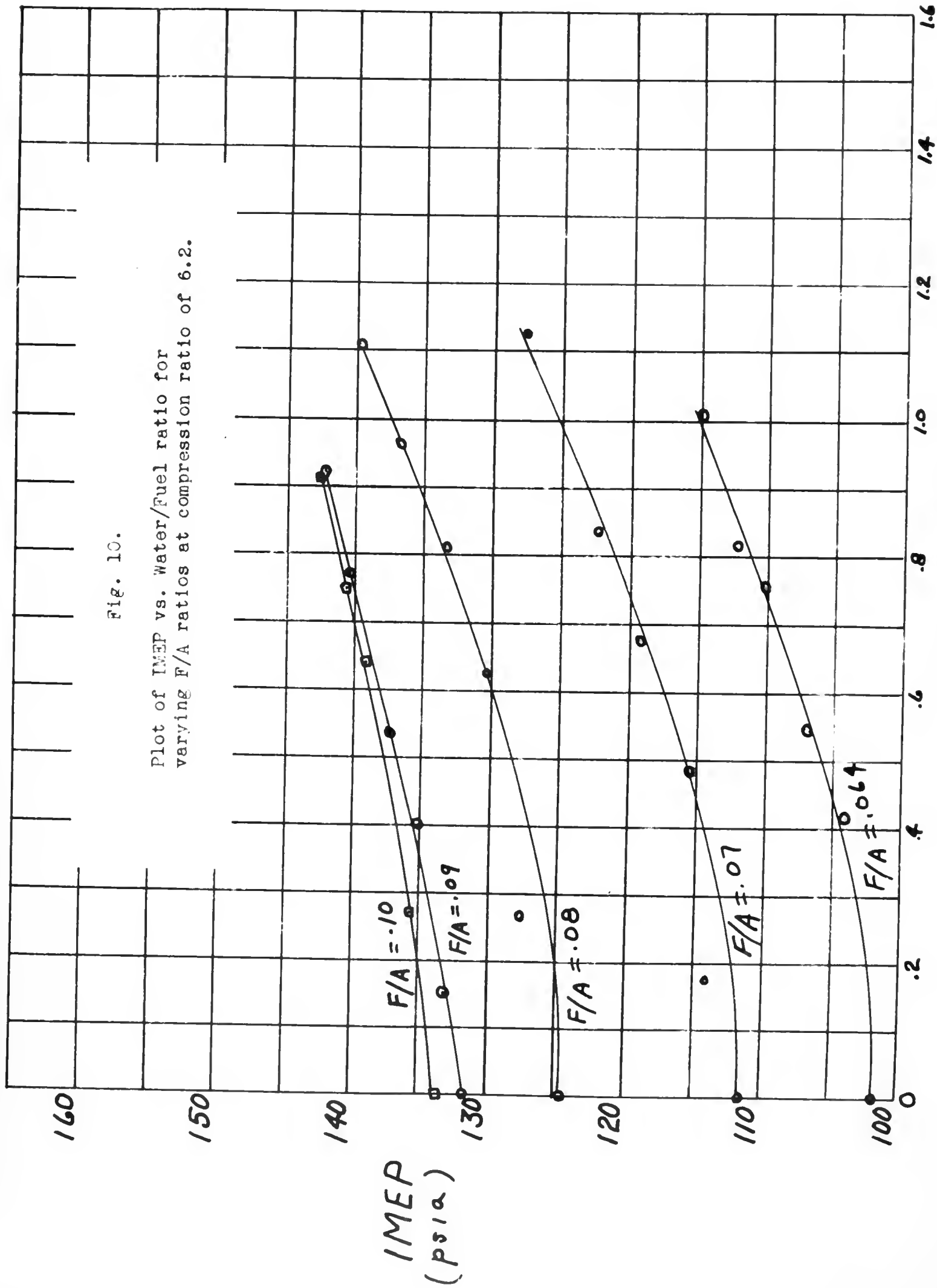


Fig. 9.  
Variation of length of  
water injection period  
with water flow.

T.C.  
10 DEGREES AFTER TOP CENTER, X.  
20  
30  
40  
50





$$\frac{W}{F} = \left( \frac{\text{lbs. H}_2\text{O}}{\text{lb. Fuel}} \right)$$



Fig. 12.

Plot of IMEP vs. Water/Fuel ratio for  
varying F/A ratios at compression ratio 7.0.

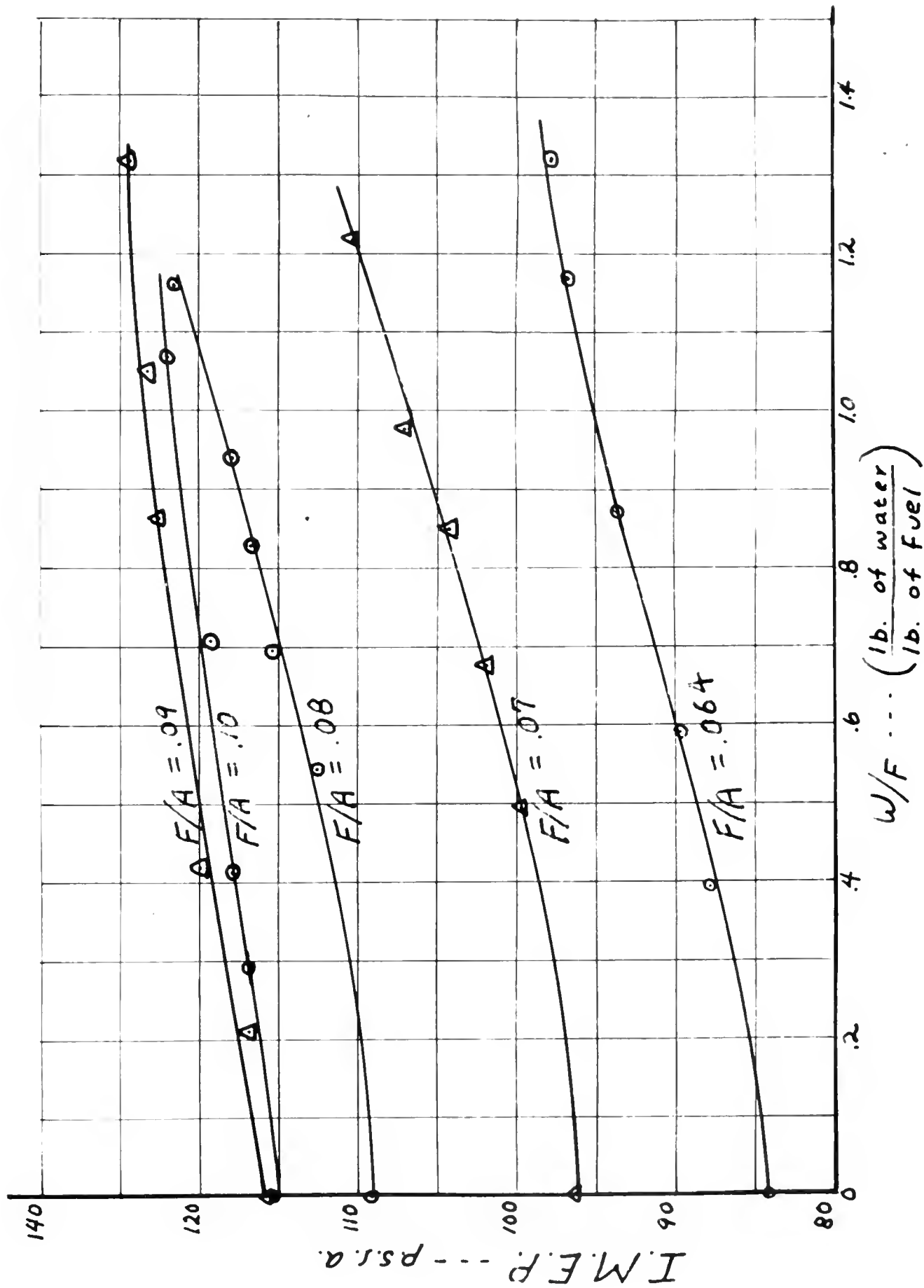
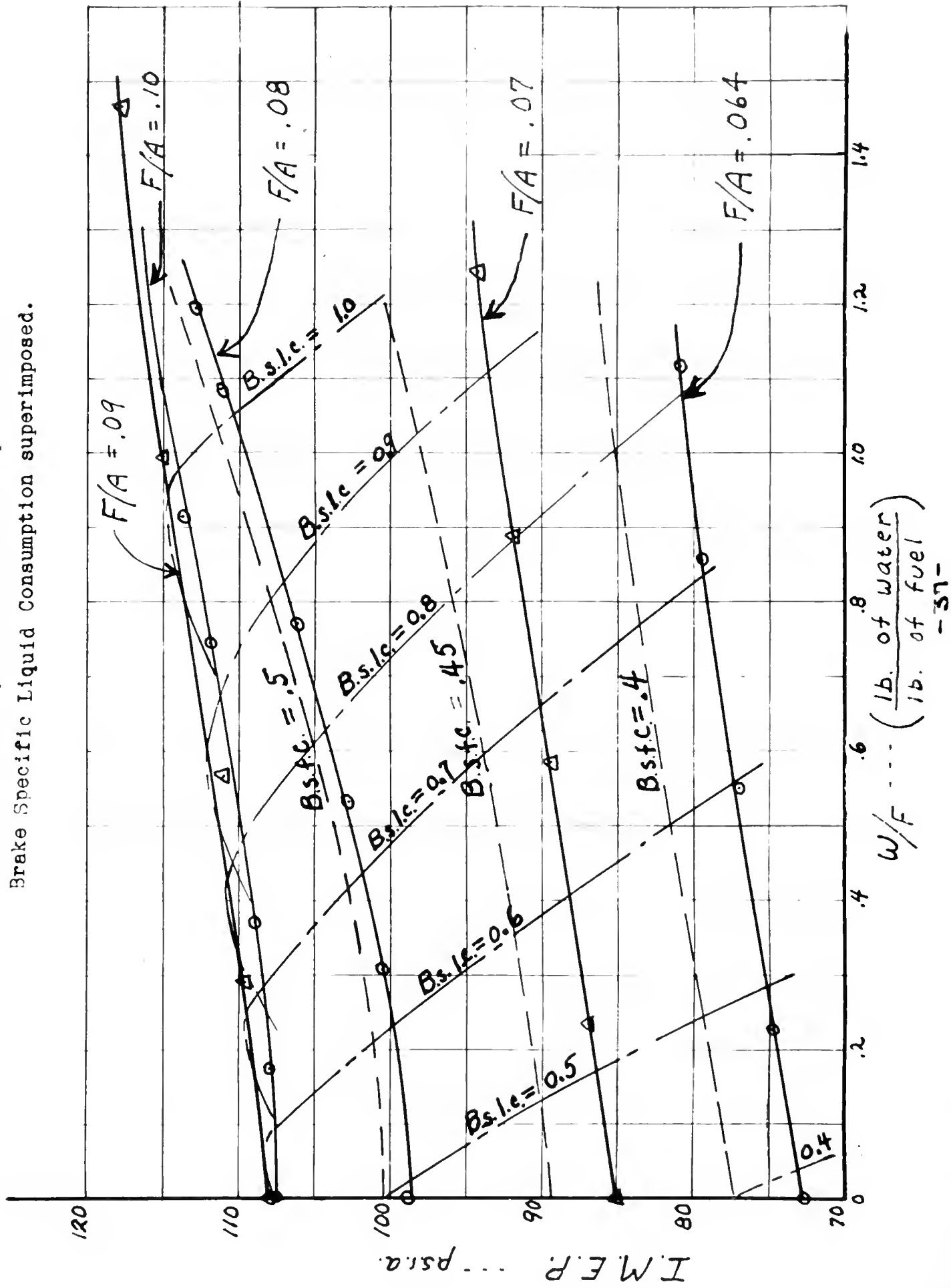




Fig. 13.

Plot of IMEP vs. Water/Fuel ratio for varying F/A ratios at compression ratio 7.4. Lines of constant Brake Specific Fuel Consumption and Brake Specific Liquid Consumption superimposed.







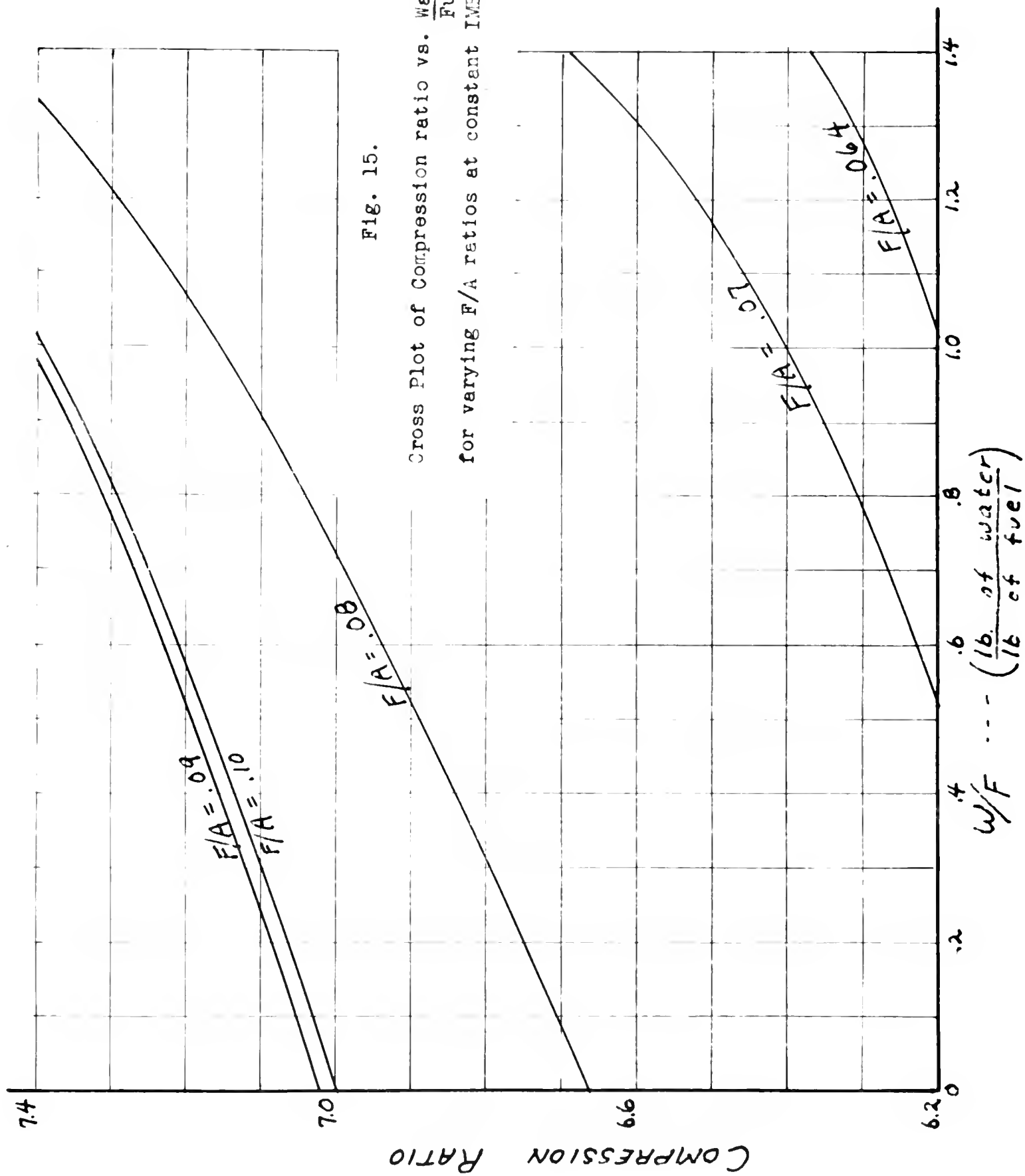


Fig. 15.

Cross Plot of Compression ratio vs.  $\frac{\text{Water}}{\text{Fuel}}$  ratio  
for varying F/A ratios at constant IMEP of 115 psia.













## DATE DUE

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